37. *The* Pliocene Deposits *of the* East *of* England.—Part II: *The* Crag *of* Essex (Waltonian) *and its* Relation *to that of* Suffolk *and* Norfolk. By F. W. Harmer, Esq., F.G.S. *With a* Report *on the* Inorganic Constituents *of the* Crag. By Joseph Lomas, Esq., F.G.S. (Read May 9th, 1900.)

Contents.

I. Introductory.

Searles V. Wood, as is well known, regarded the shell-bed of Walton-on-the-Naze, with its strongly-marked southern fauna, as older than any other part of the Red Crag, grouping the rest of that formation, in which northern shells occur more or less abundantly, under the name of the Crag of Sutton and Butley,[1] although he believed that of the latter locality to be the newer of the two.[2] Prestwich, on the other hand, maintained that all the Red Crag beds, and to some extent the Norwich Crag also, were contemporaneous[3]; and this view is, I believe, still held by no less an authority than the ex-President of the Geological Society.[4] In the face of such a difference of opinion, it seemed to me necessary to return to the subject, in order that, if possible, some more definite conclusions might be arrived at. In the hope therefore of obtaining further evidence as to the correct classification of these beds, I have spent my leisure time during the past five or six years in revisiting every part of the Crag district, and in the examination of all the more important collections of Crag fossils.

The view that the Red Crag deposits are all of the same age appears, at first sight, not unreasonable, though it is not so easy to understand why those of the Norwich Crag should have been grouped with them. As to the former, many, perhaps most, of their more characteristic mollusca are found in every part of the formation, so that lists of fossils from different localities present a striking resemblance to each other.

[1] 'Suppl. Crag Moll.' Monogr. Pal. Soc. (1872–74) p. 203, & elsewhere. S. V. Wood, Jun. and I expressed a similar opinion in the same work, p. vii. At that time we did not see our way satisfactorily to separate the Sutton and Butley deposits. [2] Quart. Journ. Geol. Soc. vol. xxii (1866) p. 538.

[3] *Ibid.* vol. xxvii (1871) p. 325. Prestwich believed, however, that in many of the Red Crag exposures an upper division could be traced, but he did not attempt to show that it contained mollusca different from those of the underlying beds.

[4] Proc. Geol. Assoc. vol. xv (1898) p. 443.

The evidence which I have collected shows, however, that some of these species are not equally common throughout, and that horizons in the Crag may be established whereat certain forms, extinct or southern for the most part, seem to have been dying out, or to have disappeared; while others, generally recent or northern, were appearing for the first time, or becoming more abundant. Moreover, the proportion between recent and extinct, and northern and southern shells at different spots varies considerably, all the evidence pointing consistently in the same direction.

Speaking generally, the molluscan fauna of any Red or Norwich Crag locality resembles most nearly that of the parishes immediately adjoining it; while from Walton-on-the-Naze, at the southern limit of the district, to Weybourn, on the northern coast of Norfolk, the Crag-beds assume a more recent and a more boreal character as we trace them northward.[1]

That these deposits arrange themselves in horizontal rather than in vertical sequence is shown by the fact that, so far as the evidence goes, the more recent Red Crag strata are not underlain by those of an earlier stage, nor do Norwich Crag beds ever rest upon Red Crag.[2] For example, the former were pierced in borings at Southwold[3] and Beccles,[4] and proved to be 147 feet and 80 feet thick respectively at those places; but at neither was the latter met with, the mollusca obtained being all of the usual Norwich Crag type. Instances of the overlapping of beds belonging to the same division of the Crag, but to a slightly different horizon, sometimes occur, however, as at Walton and Beaumont, and at the Norwich Crag pit on Bramerton Common.

In Holland, the Pliocene beds, perhaps nearly 1000 feet thick, which represent the ancient delta of the Rhine and its affluents, include a vertical and apparently continuous succession of strata from Diestian to Amstelian. In Belgium, on the contrary, deposits originating nearer to the then existing margin of the North Sea, and belonging to distinct and disconnected horizons, occupy, more or less, different areas: periods of disturbance having been followed by periods of repose, during which only deposition took place in that region.

Similarly, the Red Crag deposits of East Anglia do not form an unbroken sequence, but may be referred to three (or perhaps to four) principal stages, of which the faunas, although possibly not entirely contemporaneous, are sufficiently distinct to justify their separate classification.[5]

The term Red Crag, including, as I believe it does, beds differing considerably in age, is vague, and when we attempt to correlate the East Anglian deposits with those of other countries, inconvenient:

[1] The Coralline Crag and the estuarine Chillesford Beds are, however, for obvious reasons, exceptions to this rule.

[2] See footnote, p. 721. [3] Mem. Geol. Surv. (1887) Southwold p. 79.

[4] *Ibid.* Norwich (1881) p. 156.

[5] The deposition of the Norwich Crag was, however, as I shall endeavour to show farther on, of a similarly continuous character to that of the Dutch deposits.

the Scaldisian zone of Belgium, for example, with its southern fauna, representing one portion of it, and the Amstelian of Holland, in which arctic shells occur, another. It seems desirable, therefore, while retaining it for general use, to adopt for its various horizons some more definite and distinctive names. In a paper read before the British Association at Dover, in 1899, published in abstract only, I proposed the classification tabulated on p. 708 for the Pliocene deposits of the East of England.

The Coralline Crag (Gedgravian[1]) has been hitherto referred to the Older, and the Red Crag, including the Walton zone, to the Newer Pliocene period, the former being regarded as equivalent to the Plaisancian deposits of Italy.[2]

At the time of the publication of Wood's Supplement in 1872, there seemed good reason for this classification, as more than one-half of the species known from the Coralline Crag had not then been found in the Red, but a large number of these have since been obtained from the latter (50 by myself during the last three years at Beaumont and at a new locality at Little Oakley, in Essex); and increased knowledge of these formations has always tended to diminish rather than to emphasize the distinction between them.

Most of the characteristic Coralline Crag species are now known to occur in the Waltonian Beds, the exceptions being principally either forms which are rare or unique in the Coralline Crag, or small shells that might have been brought from some distance into the Crag area by currents from the south, which I think prevailed at the earlier period. The principal difference between the Coralline and Walton horizons is that the Waltonian Beds contain a number of mollusca which, during the interval separating the two periods, had invaded the Crag basin, presumably from the north, owing probably to the opening-up of communication with northern seas by the tectonic movements referred to in my former papers.[3] A reference to the synoptical analysis on p. 725 will show that palæontologically there is not more difference between the Coralline and Walton Crags than there is between the latter and other later zones. I doubt therefore whether the Coralline Crag is as old as the Plaisancian,[4] and am inclined to draw the line separating

[1] Gedgrave is the only locality in the Crag district where none but Coralline Crag deposits occur.

[2] See, for example, C. Reid, 'Pliocene Deposits of Britain' Mem. Geol. Surv. (1890) p. 223.

[3] With one or two exceptions, the Red Crag forms unknown from the Coralline Crag cannot be regarded as modified descendants of species belonging to the latter, and they must therefore have emigrated from other seas. Some of these, however, had reached the Belgian area as early as the Diestian Period: as, for example, *Nassa reticosa*, *Natica hemiclausa*, *Astarte obliquata*, and *Tellina Benedenii*. Mr. P. F. Kendall informs me that he has found a specimen of *Nassa reticosa* in the Coralline Crag at Gedgrave.

[4] Even allowing for the difference in latitude, the correspondence between the fauna of the Coralline Crag and that of the Plaisancian does not seem to me to be very close. From time to time I have made collections from the latter at Bordighera, Cannes, Biot, etc.; but I found that comparatively few of the fossils so obtained, presumably the characteristic forms of these deposits, are known from the Coralline Crag.

Proposed Classification of the Pliocene Deposits of the East of England.

			English Localities.	Belgian and Dutch Equivalents.
NEWER PLIOCENE.				
Cromerian.	Cromer Beds (so-called Forest-bed Series). Zone of *Elephas meridionalis*. Freshwater and estuarine.)		Kessingland, Corton, Norfolk coast from Happisburgh to Weybourn.	
Weybournian.	Zone of *Tellina balthica*. (Marine.)		Crostwick, Rackheath, Wroxham, Belaugh, Weybourn, and the Cromer coast.	
Chillesfordian.	Chillesford Clay and Sand. Zone of *Leda oblongoides*. (Estuarine.)		Chillesford. Various localities in Norfolk and Suffolk.	
Icenian.	Norwich Crag. (Marine.)	Upper Division. Zone of *Astarte borealis*.	Easton Bavent, Yarn Hill, Aldeby, Bramerton, Thorpe near Norwich, Postwick, Brundall, Horstead, Coltishall, Burgh, Wroxham.	
		Lower Division. Zone of *Mactra subtruncata*.	Aldeburgh, Thorpe (Suffolk), Dunwich, Bulchamp, Southwold, Beccles, Ditchingham.	
Butleyan.	Red Crag. (Marine.)	Zone of *Cardium grœnlandicum*.	Sudbourn, Chillesford, Iken, Butley, Boyton, Bawdsey, Alderton, Hollesley.	Amstelian. Upper part.
Newbournian.		Zone of *Mactra constricta*.	Suffolk, between the Rivers Orwell & Deben, and Ramsholt, Sutton, Shottisham.	
?		?	Bentley, Tattingstone, and the district between the Rivers Stour & Orwell.	Amstelian. Lower part.
Waltonian.		Oakley Horizon. Zone of *Mactra obtruncata*.	Beaumont, Oakley, Dovercourt, Harwich.	Poederlian.
		Walton Horizon. Zone of *Neptunea contraria*.	Beaumont, Walton-on-the-Naze.	Scaldisian—Zone à *Trophon antiquum* (*Chrysodomus contraria*).
Gedgravian.	Coralline Crag.	Zone of *Mactra triangula*.	Tattingstone, Sutton, Ramsholt, Boyton, Gedgrave, Sudbourn, Orford, Iken, Aldeburgh.	Casterlian—Zone à *Isocardia cor*.
OLDER PLIOCENE.				
Lenhamian.	Lenham Beds.	Zone of *Area diluvii*.	Lenham, Harrietsham, Charing, Paddlesworth, Folkestone.	Diestian. Waenrode Beds?
	Boxstone Fauna.		Base of Red Crag. Base of Coralline Crag at Sutton.	

It must be understood that the species mentioned above as specially characteristic of certain horizons are only locally so. Most of them are species still living, though not now, with two exceptions, in the Anglo-Belgian area. The distribution of mollusca during the Pliocene period, as at present, was largely a matter of latitude.

the Newer from the Older Pliocene between the Lenham Beds (containing *Arca diluvii*,[1] and other characteristic Italian Pliocene or Miocene shells of the North Sea basin) and the Coralline Crag, regarding the latter as the oldest member of a more or less continuous and closely connected series of Newer Pliocene age.

The Gedgravian Beds seem to be approximately equivalent to the Belgian zone à *Isocardia cor*, as suggested by M. Van den Broeck. The Lenham and Folkestone Beds, on the other hand, not only closely resemble the sands of Diest and Louvain lithologically, but are connected stratigraphically with them by a more or less continuous chain of outliers always occupying high ground, as pointed out by that observer. He formerly separated the Antwerp Beds à *Isocardia cor* from the Diestian Sands under the term Casterlien[2] (originally proposed by Dumont), and I suggest that it might be desirable to revive that classification. If, as I think, the Lenham deposits are distinct from the Coralline Crag, the zone à *Isocardia cor* may be equally distinct from the ferruginous sandstones of Belgium.

II. The Crag of Essex—Waltonian. (See Map on p. 710.)

The Red Crag beds for which I propose the term Waltonian are confined to the county of Essex, and are distinguished, as is the Walton deposit, by the strongly marked southern facies of their molluscan fauna, and especially by the abundance of the southern species, *Neptunea contraria*, and the absence, except in the Oakley sub-zone as explained farther on, of the dextral form, *Neptunea antiqua*,[3] and its northern allies *N. despecta* and *N. carinata*. The study of the comparative abundance of these two groups at different horizons in the Crag is of considerable importance. The sinistral species, so characteristic of the Essex Crag, becomes less abundant at the various exposures in Suffolk as we trace them northward, and it is rarely met with in Norfolk. The dextral shell, on the contrary, almost unknown at the Walton horizon, is increasingly

[1] I am not aware that any species, which is as specially characteristic of the Coralline Crag as *Arca diluvii* is of the Lenham Beds, can be pointed out as absent from Walton.

[2] 'Diestien, Casterlien & Scaldisien,' Ann. Soc. Roy. Malac. Belg. vol. xvii (1882) Bull. pp. ciii–cviii.

[3] I have given elsewhere, Proc. Internat. Congr. Zool. Cambridge (1898) p. 222, my reasons for believing that *Neptunea antiqua* and *N. contraria* are not varieties of the dextral form as now generally supposed, but, as originally described by Linnæus, distinct species. These migrated separately into the Crag area from the north, *N. contraria* arriving at an earlier period, and penetrating during the Pliocene epoch farther southward than *N. antiqua*. At present, moreover, the sinistral shell is not known living farther north than Vigo Bay, on the western coast of Spain; while the dextral *N. antiqua*, and especially its carinated representatives, have a northern range. The reversed specimens of *N. antiqua* occasionally met with in British seas are doubtless monstrous varieties of the dextral shells with which they occur, and which they closely resemble. The sinistral shells of the Crag, on the contrary, are allied to the species now living in Vigo Bay, and to *N. sinistrorsa* of the Sicilian Pliocene. No reversed (that is, dextral) specimens of the Crag form *N. contraria* have ever been met with.

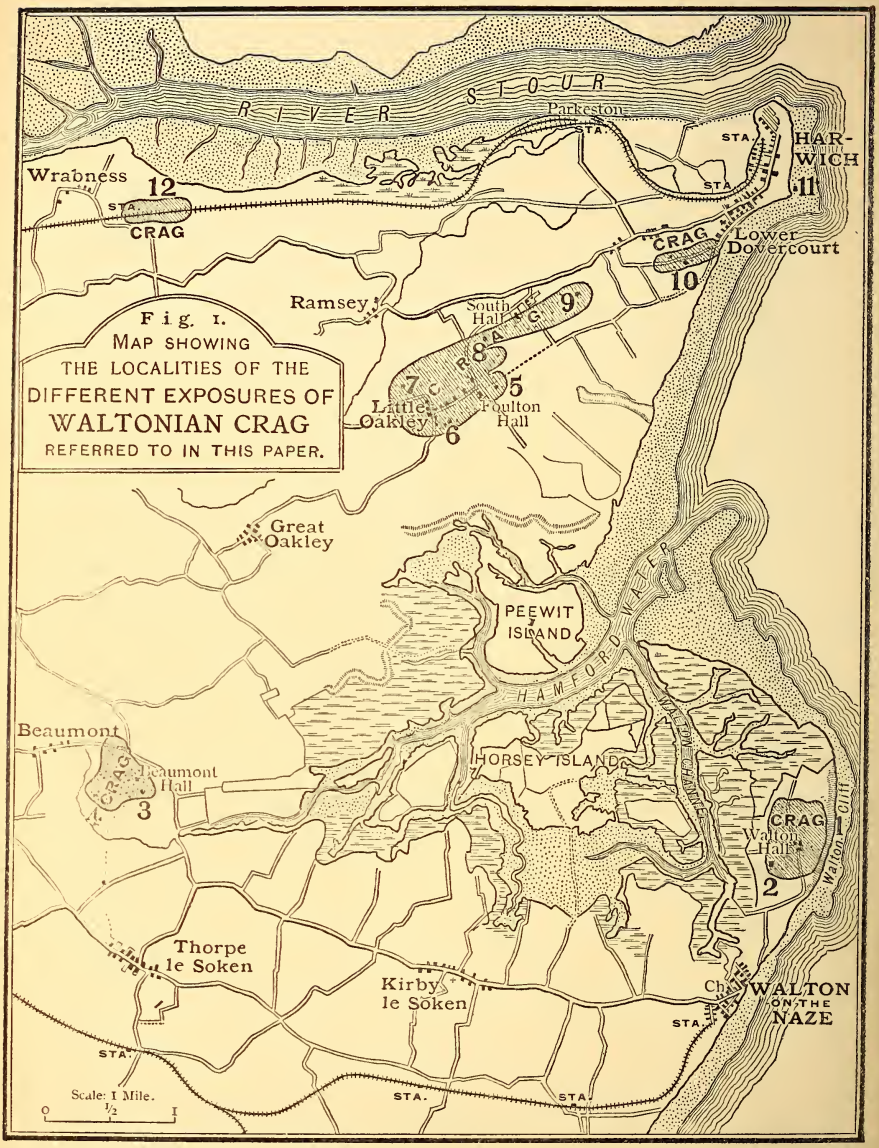


Fig. 1.
MAP SHOWING
THE LOCALITIES OF THE
DIFFERENT EXPOSURES OF
WALTONIAN CRAG
REFERRED TO IN THIS PAPER.

common in the northern part of the Crag area; and the varying proportion between the two at different localities coincides everywhere with that between the southern and northern, and the extinct and recent species of mollusca.

The most important and best-known exposure of Crag in the county of Essex is that of the long cliff-section at Walton-on-the-Naze (marked 1 on the map, fig. 1, p. 710)[1]. There is also a large pit near that town at the spot marked 2, which is now overgrown, but it could be easily opened if permission were obtained.[1]

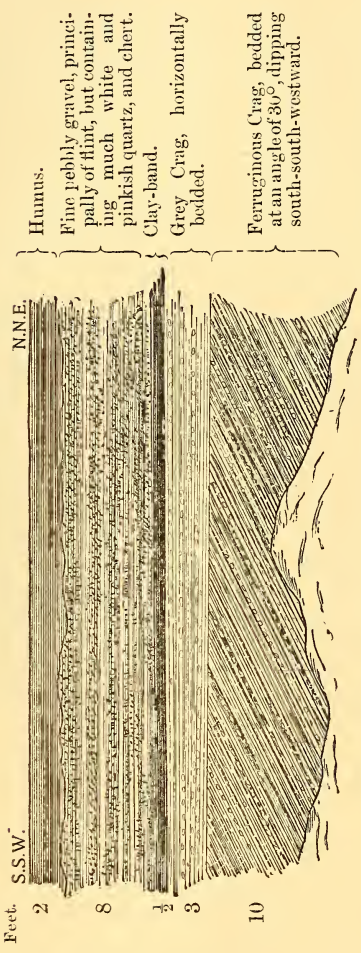


Fig. 2.—*Section at Walton Cliff.*

In his First Supplement to the 'Monograph of the Crag Mollusca'[2] Searles V. Wood gave a list of 148 species of mollusca known to him from Walton, a large proportion of them being extinct or southern forms; and in his Second and Third Supplements[3] about 50 more were added, principally on the authority of the late Robert Bell. Some years later, Mr. P. F. Kendall worked at Walton for a considerable time, increasing the list of shells to about 320.[4] His researches, with those of other observers, have, however, confirmed Wood's view of the southern as well as the older character of the Walton fauna.

Unfortunately, at present and for some years past the cliff-section has been obscured by talus, and visible only at a few isolated spots;

[1] It would be more useful, and more interesting also, if collectors would devote their efforts to these less-known Crag localities, rather than to the few pits to which continuous attention has been paid during so many years.

[2] Monogr. Pal. Soc. (1872) pp. 203–19. [3] Monogr. Pal. Soc. (1879 & 1882).

[4] Mr. Kendall has very generously offered to allow me to incorporate this list with that of the species obtained by me from Beaumont and Little Oakley, which will very much increase the value of the latter to students of the Crag.

but fig. 2 (p. 711) represents a portion of it exposed at two localities, at no great distance apart, the succession of beds being the same at each.

The upper part of the Crag now shown at this place is of a grey colour, and is horizontally stratified; while the lower part is ferruginous, and obliquely-bedded at an angle of about 30°, the laminæ dipping south-south-westward. This oblique bedding was noticed by Searles V. Wood, Jun. at Walton and elsewhere thirty-six years ago,[1] and it has, I think, an important bearing on the question of the conditions under which the Red Crag originated. An unstratified shell-bed, described by him in the same paper as resting upon the London Clay, with the remains of mollusca in an undisturbed position of growth, is not now visible.

The upper part of the cliff-section is occupied by a bed of sandy gravel, made up chiefly of flint, but containing also pebbles of various kinds of quartz (pink and white), and of chert. This is underlain by a band of grey sandy clay, which has been considered as possibly of Chillesford age.[2] The clay and the gravel are, however, more or less conformable one to the other and to the underlying Crag, and I am inclined to think that both of the former may be of Red Crag age. This view has been recently confirmed by my friend Mr. Lomas, who has discovered that the sandy portion of the gravel is identical in composition with that of the Crag.

From Walton southward the cliff is composed of London Clay, with a few obscure traces of gravel over it; between Little Holland and Clacton-on-Sea similar pebbly beds occur in the coast-section, but in much greater thickness than at Walton, extending for 3 miles or more to the north of Clacton (see map, fig. 3, p. 714). I suggest that these gravels may be either fluviatile or estuarine, brought down by a river which ran from the south-west at some period later than that of the deposition of the Walton shell-bed, when the southern margin of the Crag sea had retreated northward.[3]

The species of mollusca which I consider most characteristic of the Walton Crag are as follows:—

Cypræa avellana.
—— *europæa.*
Voluta Lamberti.
Columbella sulcata.
Nassa labiosa.
—— *propinqua.*
—— *elegans.*
—— *granulata.*
—— *reticulata* and varieties.
Buccinopsis Dalei
Buccinum undatum.
Purpura lapillus var. *intermedia.*
—— *tetragona* var. *alveolata.*
Trophon (*Neptunea*) *contrarius.*
—— (——) *costifer.*
—— (*Sipho*) *gracilis.*
—— (——) *Olavii.*
—— (——) *muricatus.*
Pleurotoma mitrula.
Cerithium tricinctum.
Turritella incrassata.
Lacuna subaperta.
Natica catenoides.
—— *hemiclausa.*
—— *millepunctata.*
Trochus cineroides.

[1] Ann. & Mag. Nat. Hist. ser. 3, vol. xiii (1864).
[2] See Mem. Geol. Surv. (1877) 'Eastern End of Essex (Walton-on-the-Naze & Harwich)' p. 13.
[3] If this view be correct, the clay-bed is not of Chillesford age.

Trochus noduliferens.
—— *subexcavatus.*
—— *Adansoni.*
—— *Montacuti.*
Fissurella græca.
Emarginula fissura.
Calyptræa chinensis.
Capulus ungaricus.
Tectura virginea.
Actæon Noæ.
Conovulus pyramidalis.
Anomia ephippium.
Ostrea cochlear.
Pecten opercularis.
—— *pusio.*
Mytilus edulis.
Pectunculus glycimeris, especially var. *subobliquus.*
Nucula lævigata.
Montacuta bidentata.
Scintilla ambigua.
Lucina borealis.
Cardita corbis.
—— *scalaris.*
—— *senilis.*
Cardium edule.
—— *Parkinsoni.*
Cyprina islandica.
Astarte obliquata.
—— *Galeottii.*
—— *Burtinii.*
Woodia digitaria.
Artemis lentiformis.
Mactra arcuata.
Solen ensis.
—— *siliqua.*
—— *gladiolus.*
Corbula gibba.
Corbulomya complanata.
Pholas crispata.
—— *cylindracea.*

The majority of the foregoing species are either extinct or southern forms.

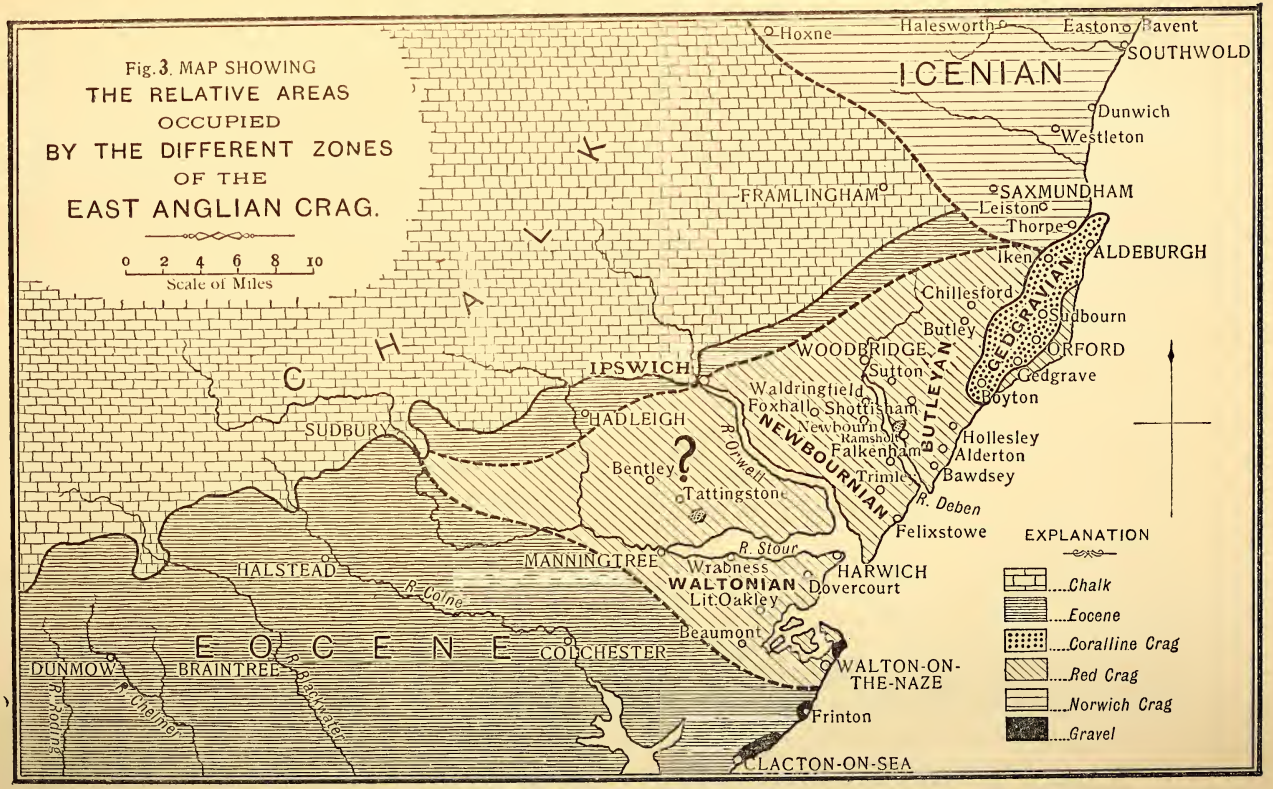
A number of northern or recent species, which became more or less common in the later beds of the Red Crag, are moreover absent or rare at Walton; of these I may mention:—

Buccinum grœnlandicum.
Trophon (Neptunea) antiquus (dextral).
—— *despectus.*
—— *scalariformis.*
—— *altus.*
Purpura lapillus (the existing form).
Cancellaria viridula.
Turritella terebra.
Scalaria grœnlandica.
Littorina littorea.
Natica clausa.
—— *catena.*
—— *grœnlandica.*
Trochus formosus.
—— *tumidus.*
Modiola modiolus.
Nucula Cobboldiæ.
—— *tenuis.*
Leda oblongoides.
—— *lanceolata.*
Cardium angustatum.
—— *grœnlandicum.*
Astarte compressa.
—— *sulcata.*
Tellina obliqua.
—— *prætenuis.*
Mactra ovalis.
—— *constricta.*

None of the foregoing species are known from the Crag of Normandy, or from any Older Pliocene beds south of Great Britain.

A very few specimens only of some of them have been found at Walton; but they are the rare exceptions, not the rule, and were the vanguard, so to speak, of the molluscan army which at a subsequent period invaded the Crag basin from the north.

Adopting, as I have always done, Wood's opinion as to the comparatively early age of the Walton Crag, and its marked distinction from that of Suffolk, it seemed to me important, as a crucial test of the hypothesis that the upper Crag deposits were the littoral accumulations of a sea gradually retreating northward, to re-examine the district between Walton and the estuary of the Stour, in order to see whether any beds of intermediate character could there be found, which might serve to bridge over the gap separating the Walton Crag from that of Suffolk.



Note: South of the River Stour the Red Crag has been much denuded.

I was fortunate enough to find such a deposit in the first instance, at Beaumont, 5 miles west of Walton. The section at that locality, described more than fifty years ago by the late John Brown of Stanway, has been closed for many years, but it has been recently reopened.[1] Brown obtained about 100 species of mollusca from this spot, and his list, originally appearing in a pamphlet printed for private circulation, was afterwards republished by Mr. Whitaker in his Survey Memoir.[2] Unfortunately the names of *Astarte borealis* and *Tellina lata*, arctic shells characteristic of the newest horizons only of the Crag, were included,[3] and no distinction was made between rare and abundant forms, so that the Beaumont deposit has been referred, not without justification, to the latest part of the Red Crag.[4] When studied on the spot, however, it will be clear, I think, that, though possibly slightly newer, it is of similar age to that of the Walton bed. I have lately obtained more than 260 species from Beaumont, and I find that, with very few exceptions, those mentioned on pp. 712–13 as characteristic of the Walton Crag, occur there more or less abundantly.

While the molluscan fauna of the Beaumont Hall pit resembles so closely that of Walton Cliff, there are some points of difference between the two. A few northern shells are present at the former locality which are wanting or are exceedingly rare at the latter. *Natica clausa* is found occasionally at Beaumont, but only one specimen, so far as I know, has been recorded from Walton. *Tellina prætenuis*, allied to, though distinct from, the arctic form, *T. lata*, is regarded as an extinct species; but it came into the Crag sea with the northern mollusca, and waxed abundant in it as they did. It is not uncommon at Beaumont, though almost unknown at Walton. The general facies of the Beaumont fauna, however, is decidedly southern.[5]

Through the kindness of A. H. Stanford, Esq., of Beaumont Hall, I was allowed to open a hole at a spot marked 4 on the map (fig. 1, p. 710), near the south-western limit of the Beaumont outlier. This showed from 5 to 6 feet of Crag, resting upon the London Clay, the junction of the two dipping sharply south-westward. The surface of the ground slopes rapidly in the same direction, with the result

[1] There is an inn at Thorpe-le-Soken where fairly comfortable accommodation may be obtained. From Thorpe a short cut strikes across the fields to Beaumont. Leave to visit the Crag-pit should, however, be obtained from Mr. Stanford.

[2] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 26.

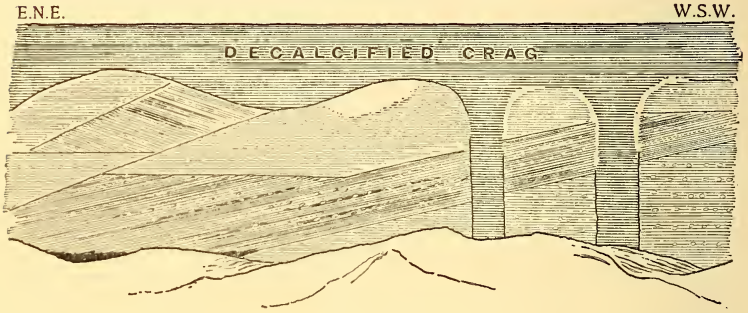
[3] Brown mentions two species of *Tellina* only:—*T. obliquata* and *T. ovata*; these appear in Mr. Whitaker's list as *T. obliqua* and *T. lata*. The forms present at Beaumont are, however, *T. obliqua* and *T. prætenuis*. The specimens referred by Brown to *Astarte borealis* may have been worn examples of *A. Basterotii*. *A. borealis* has not been found, so far as I know, south of Easton-Bavent, nearly 40 miles from Beaumont, where it occurs in beds of Upper Norwich-Crag age.

[4] Mem. Geol. Surv. (1890) 'Plioc. Dep. of Britain' p. 85.

[5] Two characteristic Coralline Crag and southern species, *Cardita corbis* and *Woodia digitaria*, for example, are present at Beaumont in the most extraordinary profusion.

that the base of the Crag, instead of being water-logged and stained, as at the other pit, is as dry as powder and quite white, having been unaffected by the infiltration which has given to the part above it the usual rusty hue of the Red Crag.[1] From pit No. 4 I obtained several species which I did not notice at No. 3, namely: *Mactra obtruncata* (very common), *Purpura lapillus* var. *intermedia*, with one adult and two or three young specimens of *Neptunea antiqua* (dextral), and of its northern variety *carinata*. These are all characteristic of the still newer deposit at Little Oakley to be described farther on (p. 739). While *Neptunea contraria* is most abundant at Beaumont, the dextral form, *N. antiqua*, is very rare at pit No. 3. With the help of a labourer, about 7 or 8 tons of Crag were sifted there, but only one perfect specimen and one small fragment of the latter species were met with.[2]

Fig. 4.—*Section of Waltonian Crag near Beaumont Hall.*



The fossils have been removed from the upper portion of the Beaumont section by infiltration, but the carbonate of lime so derived has been redeposited on the surface of the unaltered Crag, and along the edges of pipes which are filled with material similar to that of the decalcified portion. The Crag is partly false-bedded, with an east-north-easterly dip, but the inclination of no part of the bedding is so great as that of the beach-like Crag at Walton and elsewhere. The base of the deposit where it rests upon the London Clay is black (see Mr. Lomas's Report, p. 738). Although the Crag outlier caps the summit of a hill, whence the ground slopes rapidly towards Thorpe, water stands constantly at the bottom of the pit, even during the summer, showing that the surface of the underlying London Clay is more or less cup-shaped.

Pursuing my investigations in a northerly direction, I found at

[1] This tends, I think, to show that the staining of the Red Crag has taken place, in some cases at least, in comparatively recent times.

[2] Right-handed specimens are quite unknown to the farm-labourers at Beaumont. This is not only a matter of common observation among them, but they have formulated a theory to account for it: 'Before the Flood, everything was left-handed.'

Foulton Hall, Little Oakley, midway between Beaumont and Harwich (about 4 miles from each place), a shallow section (No. 5 in the map, fig. 1, p. 710), showing only 1 or 2 feet of dirty-looking horizontally-bedded Crag, which, although its existence was known both to S. V. Wood, Jun.,[1] and to Mr. Whitaker,[2] had received hitherto no attention from collectors. It has revealed, however, an exceedingly rich and interesting fauna, generally similar to that of Walton and Beaumont, and distinctly southern. This fauna includes nevertheless a larger proportion of northern forms than is found at those places, representing the somewhat later period before the southern shells had commenced to disappear, when boreal mollusca were beginning to establish themselves, in greater or less abundance, in the Pliocene basin.

As the Crag of Little Oakley appeared to be different in age from anything previously known, I determined to work it out as thoroughly as I could. By the kindness of Gilbert Purvis, Esq., of Foulton Hall, I was allowed to excavate and sift over an area 10 yards in length by 3 in breadth, obtaining in so doing more than 350 species and well marked varieties of fossils,[3] some of them new to science, and many of them known to Wood from the Coralline Crag only.[4] The presence of so large a number of distinct forms in one seam, little more than 12 inches thick, and only 10 yards long, constitutes a striking illustration of the extraordinary richness of the molluscan fauna of the North Sea at that period.[5]

Among the boreal forms present at Oakley I may mention:— *Trophon scalariformis*, *Tr.* (*Sipho*) *gracilis*, and its allies *Tr. Olavii*, *Tr. gracilis* var. *convolutus*, *Tr. Sarsii*, *Tr. Jeffreysianus*, and *Tr. islandicus*, and *Trochus formosus*, which are all more abundant there than they are at Beaumont, as are also *Natica clausa*, *Mactra obtruncata*,[6] *Tellina obliqua*, and *T. prætenuis*. The northern shells, *Trophon barvicensis*, *Admete viridula*, *Scalaria grœnlandica*, *Modiola*

[1] MS. 1-inch map in the Geological Society's Library (about 1864).

[2] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 14.

[3] The occurrence, or otherwise, of so-called varieties at the various Crag localities is of considerable importance, and should always be noted. For example, *Purpura lapillus* is said to occur at all horizons of the Upper Crag, but the variety specially characteristic of the Oakley bed [at present undescribed, but which I propose to call *intermedia*] is very different from the existing shell, while that of the much more recent Norwich Crag is identical with it. The distinction between species and varieties is, moreover, quite arbitrary. Many so-named varieties of Crag species, as, for example, those of *Nassa reticosa*, differ more widely one from the other than do other Crag forms which are generally regarded as specifically distinct.

[4] The Crag-pit at Foulton Hall is no longer available: I was compelled to level it down as the work proceeded. I shall be pleased, however, to show my specimens to any student of the Crag, and I propose eventually to place them in the Museum at Norwich.

[5] The present molluscan fauna of the North Sea is much poorer than this. During a recent visit to the shell-beaches of the Dutch coast, I noted less than 30 species, and not more than about 100 have been recorded as now living near the shores of Norfolk, many of them being very rarely met with.

[6] *Mactra obtruncata* is abundant in the upper part of pit No. 4 at Beaumont.

modiolus, and *Astarte compressa* are found at Oakley, though not frequently. On the other hand, the southern forms *Cardita corbis* and *Woodia digitaria* are somewhat less common at Oakley than at Beaumont.

A noteworthy feature of the Oakley fauna is, the occurrence in it, though not abundantly, of *Neptunea antiqua* (dextral). Of the carinated and peculiarly northern forms of this shell I have found there more than a score of examples,[1] principally young, and one of an exceedingly short-spired variety, *brevispira*.[2] These earliest recorded specimens of *N. antiqua* are generally short-spired, and show no signs of approaching the normal Red Crag type of *N. contraria* with which they co-existed, as they ought to do if the one were merely a variety of the other.

The presence at Oakley of *Trochus tricariniferus*, *Pecten Gerardii*, *Lima plicatula* (a single specimen only of each), and other species hitherto known from the Coralline Crag alone, is interesting, as is that of several new species of *Nassa* and *Cardita*, and of *Cancellaria mitræformis* var. *costulata*, the latter closely resembling a shell from the Italian Pliocene. Specimens of *Turritella marginalis* and *T. vermicularis* (fragmentary), also Italian Pliocene shells, have been found, as well as *Natica helicina*, a Miocene species confined, according to Wood, to Walton and Bentley.

The Little Oakley outlier probably extends over the highest part of that parish, and thence, though not continuously, along the ridge which runs towards Dovercourt Cliff, as shown on the map (fig. 1, p. 710). I was informed by an old man, resident there at the time, that coprolites were formerly dug at the spots marked 6 & 7. I noticed Crag in hedges near South Hall, at 8 & 9, and in a pit ½ mile from Dovercourt at 10 : too comminuted at the last-named, however, to yield any good results, but I ascertained by boring that the deposit is 10 feet thick, resting upon the London Clay. I found Crag also by boring at several spots between No. 10 and the cliff; in the garden adjoining the Hotel, however, and as far as can be seen along the cliff, the London Clay comes to the surface.

The small outlier formerly exposed at Harwich, near the spot marked 11 on the map (fig. 1, p. 710), now quite destroyed, seems, so far as the evidence goes, to have belonged to the Waltonian division. The figures drawn by Dale, the Father of Crag geologists,[3] are not all satisfactory, but the following species may be identified from them with more or less certainty :—

[1] M. Van den Broeck mentions a similar shell under the name of *Chrysodomus despecta* var. *carinata*, Sars, Bull. Soc. Belge Géol. vol. vi (1892) Mém. p. 131 (*Neptunea antiqua* var. *tricarinata*, Nyst, 'Conchyl. Terr. Tert. Belg.' Ann. Mus. Roy. Hist. Nat. vol. iii, pt. i, 1881), as characteristic of the Poederlian, an upper zone of the Scaldisian.

[2] Figured in Proc. Internat. Congr. Zool. Cambridge (1898) pl. iii, fig. 8.

[3] 'Hist. & Antiq. Harwich & Dovercourt' London, 1730.

Voluta Lamberti.
Nassa reticosa var. *costata.*
—— —— var. *elongata.*
Buccinopsis Dalei.
Buccinum undatum.
Purpura lapillus var. *intermedia* (the Oakley form).
Trophon costifer.
—— (*Neptunea*) *antiquus.*
—— *despectus.*
—— *contrarius.*
—— (*Sipho*) *gracilis.*
Cerithium tricinctum.
Natica catenoides.
Ostrea edulis.
Pectunculus glycimeris.
Pecten operculatis.
Cardita senilis.
Cardium edule var. *edulinum.*
—— *decorticatum.*
—— *Parkinsoni.*
Astarte obliquata.
—— 2 spp.
Cyprina islandica.
Tellina crassa.
Mactra arcuata.
—— *obtruncata (?).*
Pholas cylindracea.
Terebratula grandis.

These are all common Waltonian species. No small forms are figured by Dale, and it is strange that *Purpura tetragona* and *Artemis lentiformis*, so abundant at other localities in Essex, should not have been observed. On the other hand, had the Harwich Crag been of the same age as that of Felixstowe in Suffolk, on the opposite bank of the estuary of the Stour, forms so characteristic of the latter as the existing variety of *Purpura lapillus*, and *Tellina obliqua*, could hardly have escaped notice. We may therefore, perhaps, include the Harwich bed in the Waltonian division, and take the River Stour as the northern limit of those deposits.

It is possible that Crag may be present beneath the Middle Glacial gravel between Wrabness and Ramsey, though there is no direct evidence that such is the case. I was, however, unable to trace it between Little Oakley and Beaumont. South of the former locality it has evidently been much denuded.

The age of the patch of Crag at Wrabness (No. 12 in fig. 1, p. 710) mapped by S. V. Wood, Jun. during his survey of Essex, and mentioned by Mr. Whitaker in his Survey Memoir,[1] cannot be determined, as no list of fossils from that place is in existence.

I propose to bring before the Geological Society at an early opportunity a complete list of the mollusca etc. from the Waltonian Crag, together with a description of some new species.

III. The Relation of the Waltonian Beds to other Horizons of the Red Crag and to the Norwich Crag.

While, therefore, we may group the Beaumont, Oakley, and Harwich deposits with those of Walton, notwithstanding the slight differences between them, we find on crossing the estuary of the Stour into Suffolk, that the fauna of the Crag-beds there exposed differs from them in important particulars.

At Felixstowe, for example, only 3 miles north-east of Harwich, a number of species, extinct or southern, which are very characteristic of the Essex Crag, are more or less rare, as, for example,

[1] Mem. Geol. Surv. (1877) 'Walton-Naze & Harwich' p. 14.

Columbella sulcata, *Nassa elegans*, *Natica catenoides*, *Trochus Adansoni*, and *Nucula lævigata*; *Cardium Parkinsoni* and *Mactra arcuata* are present, but are not so strikingly abundant as they are in Essex. On the other hand, *Cardium angustatum*, a distinctive form of the Suffolk Crag, exceedingly rare in the Waltonian beds, is very common at Felixstowe, as are *Mactra ovalis* and *M. constricta*, unknown from Walton. The *Tellinæ* (*T. obliqua* and *T. prætenuis*) form at Felixstowe a distinguishing feature of the Crag, although they do not occur in such extraordinary profusion as in beds farther north; *Artemis lentiformis* is comparatively rare, and is not often found perfect. *Nucula Cobboldiæ*,[1] so characteristic of the later horizons, begins there to make its appearance, with an occasional specimen of *Leda oblongoides*. The existing variety of *Purpura lapillus* is abundant, and *P. tetragona* comparatively less so. *Neptunea antiqua* (dextral) is fairly common, though its sinistral representative still outnumbers it, perhaps by 6 to 1. I do not think that any one going direct from Little Oakley to Felixstowe could fail to recognize the difference between the two deposits.

The Felixstowe Crag closely resembles that of Waldringfield and the country lying between the Rivers Orwell and Deben, on the one hand, and that of Sutton, Ramsholt, and Shottisham, west of the Deben, on the other, with which, therefore, as proposed by Wood, it may be grouped, although the list of species recorded from Waldringfield, Foxhall, and Sutton, seems of a slightly older character than that from Felixstowe. For this division I propose the term Newbournian,[2] from Newbourn, the well-known Crag locality, where the 20-foot section, ½ mile north-east of the church, shows obliquely-bedded shelly sand, much of it dipping south-south-westward.

Among other boreal species characteristic of the later horizons of the Red Crag, which are more abundant at this zone than at Walton, may be mentioned *Scalaria grœnlandica*, *Admete viridula*, *Modiola modiolus*, and *Astarte compressa*; *Littorina littorea* appears at this stage for the first time, as does the northern form *Natica helicoides*.

The only exposures of the sheet of Crag which, overlain by Glacial deposits, appears to cover the country between the Stour and the Orwell, that have received any attention from collectors, are at Bentley and Tattingstone; but the fauna contained in them has not at present been worked out, and the exact horizon to which they should be referred cannot therefore be finally determined. S. V. Wood believed, however, that the Bentley deposit, while newer than that of Walton, was older than any other part of the Suffolk Crag.

The Crag of Butley, containing a still larger number of northern, with a smaller proportion of southern species, must, I think, be

[1] I found no trace of this shell during my many visits to Beaumont and Little Oakley.

[2] I prefer Newbournian as a name to Suttonian, for Sutton is also a well-known Coralline Crag locality.

regarded as belonging to a period distinctly later than the rest of the Red Crag.

Neptunea antiqua (dextral) is at Butley nearly as abundant as *N. contraria*. Several species of *Leda* are there met with not unfrequently, and *Nucula Cobboldiæ* is very common; while *Tellina obliqua*, *T. prætenuis*, *Mactra ovalis*, *M. constricta*, and *Cardium angustatum*, with some recent British species, are so abundant as to make up a large proportion of the total number of specimens present. The following northern shells may be noted as more abundant in the Butley zone than in beds of an earlier age, namely: *Trophon altus*, *Buccinum grœnlandicum*, *Natica grœnlandica*, and *Cardium grœnlandicum*. At the same time the proportion of extinct and southern shells is considerably smaller at Butley than in the Newbournian Crag.

There are other exposures of Crag at Alderton, Hollesley, and Bawdsey, containing a fauna similar to that of Butley, the arctic shell, *Cardium grœnlandicum*, very rare in the Newbournian deposits, being especially characteristic of the last-named locality; and for these, with the Crag of Sudbourn and Iken, and of the stack-yard pit at Chillesford,[1] I propose the name Butleyan. This division has a more recent as well as a more boreal fauna than that of the horizons before mentioned.

The distinction between the Butleyan and the Newbournian zones seems to me to be more marked than that between any of the other divisions of the Red Crag (see analysis of molluscan fauna, p. 725).

For the deposits hitherto known as Norwich Crag (an horizon of greater thickness and importance than was formerly supposed), which extend more or less continuously from Aldeburgh in Suffolk to Horstead and Burgh in Norfolk, a distance of more than 40 miles in one direction, and 20 miles, from Hoxne to Southwold, in another, I adopt the name Icenian, originally proposed for the Crag-formation generally by S. P. Woodward.[2] These beds, in places nearly 200 feet thick, occupy an entirely different area from that of the Red Crag, and contain a fauna which differs more widely from that of the latter, than the various divisions now proposed for it do one from the other.

A number of the characteristic shells, extinct and southern, of the older Crag had lingered on in the North Sea, though in gradually diminishing numbers, until the Butleyan Period, of which the following may be mentioned (but they apparently became extinct in the Crag basin before the Icenian Period, killed off possibly by the rapidly increasing cold):—

[1] I am now disposed to think, for the reasons given on p. 734, that the highest bed at this pit, containing *Scrobicularia piperata*, formerly regarded by S. V. Wood, Jun. and myself as representing the Norwich zone, belongs to the newest part of the Butleyan division.

[2] Norwich is supposed to stand on the site of the ancient *Venta Icenorum*.

Ovula spelta.
Cypræa avellana.
Columbella sulcata.
**Cassidaria bicatenata.*
Nassa labiosa.
—— *elegans.*
**Purpura tetragona.*
Trophon costifer.
—— *muricatus.*
—— *elegans.*
Plearotoma Bertrandi.
Vermetus intortus.
Trochus subexcavatus.
—— *cineroides.*
Dentalium dentalis.
Mytilus hesperianus.
Nucula lævigata.
Cardium Parkinsoni.
—— *decorticatum.*
Astarte obliquata.
—— *Galeotii.*
—— *Basterotii.*
*—— *Omalii.*
*—— *Burtinii.*
Woodia digitaria.
Cyprina rustica.
Gastrana laminosa.
Venus imbricata.
**Cytherea rudis.*
Corbulomya complanata.

The names of those marked with an asterisk may be found in old lists of Norwich Crag shells, but no trace of them has been discovered in late years, and I doubt whether the references are reliable.

In addition to these, some others, which had survived up to the Butleyan Period, and are all more or less characteristic of the Butley zone, are exceedingly rare in the Icenian Beds, namely:—

Nassa reticosa.
—— *granulata.*
—— *propinqua.*
Neptunea contraria.
Plearotoma mitrula.
Natica hemiclausa.
—— *catenoides.*
Natica millepunctata.
Cardita corbis.
—— *scalaris.*
—— *senilis.*
Cardium interruptum.
Mactra arcuata.

Among the northern species recorded from the Norwich Crag which are unknown in the Red Crag may be mentioned *Trophon Gunneri*, *Tr. berniciensis*, *Velutina undata*, *Margarita grœnlandica*, *Rhynchonella psittacea*,[1] *Leda pernula*, *Astarte elliptica*, and *A. borealis*, only the last-named, however, being abundant. While *Neptunea contraria* is very rare in this zone, *N. antiqua* (dextral) is one of its common shells.

The comparatively modern, as well as more boreal, character of the Icenian Crag is further shown by its meagre fauna of not more than 150 species in all: many of them being excessively rare, and most of the more abundant of them typical British forms.[2] Not more than about 40 are really common, and of such only 5 or 6 are not known living, the latter being characteristic of the higher rather than of the lower zones of the Crag; 2 only are southern, and 9 northern. If the list of marine mollusca (70 in all) obtained by Mr. James Reeve from one of the richest of the Icenian localities (Bramerton, near Norwich),[3] the result of many years' work, be compared with those from the Red Crag of Little Oakley or Butley, the distinction between the Red and Norwich Crags will be, I think, apparent.

[1] Mr. Alfred Bell is said to have found this species at one locality in the Red Crag.

[2] The molluscan fauna of southern seas contains a greater number of species than that of those to the north, that of the Mediterranean being richer than the fauna of British seas, and the latter than those of the arctic regions.

[3] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 457.

The commonest species of the Icenian zone are the following, nearly three-fourths of them being recent, and nearly two-thirds common North Sea forms:—

Buccinum undatum.
Purpura lapillus.
Neptunea antiqua.
Cerithium tricinctum.
Turritella incrassata.
—— *terebra.*
Littorina littorea.
Natica catena.
Pecten opercularis.
Nucula Cobboldiæ.
Leda oblongoides.
Lucina borealis.
Cardium edule.
Astarte borealis.
—— *compressa.*
Cyprina islandica.
Tellina lata.
—— *obliqua.*
—— *prætenuis.*
Mactra ovalis.
—— *subtruncata.*
Mya arenaria.
—— *truncata.*

The presence at some localities in the Icenian area of a few land and freshwater shells,[1] and of the estuarine species *Scrobicularia piperata*, has been thought to point to estuarine conditions in East Anglia during this period. The widespread area, however, which these deposits cover and their great thickness in places, seem opposed to such a view; and notwithstanding that the general facies of the fauna is more or less of an estuarine character, I am inclined to think that these beds are marine, though accumulated near the mouth of a river, possibly some tributary of the Rhine.

While the Icenian Crag thus covers a larger district than the Red Crag, and is in places of such great thickness, its character is similar throughout, the only palæontological difference of any importance by which the several beds can be divided being that the arctic species *Astarte borealis* is distinctive of the northern part of the area, for it is common near Norwich and in the Bure Valley, less so in the north of Suffolk, while it is unknown farther south, as at Aldeburgh, Bulchamp, Southwold, and Dunwich. *Tellina lata* (*calcarea*) and some other northern forms are also rather more abundant in the northern than in the southern part of the Icenian area.[2]

The estuarine Chillesford Clay and underlying sand, always highly micaceous, the latter containing at the pit behind Chillesford Church a marine fauna still more boreal than that of the Icenian deposits, which indicate a still farther northward retreat of the Crag sea and an emergence of the East Anglian area, may be distinguished by the term Chillesfordian. The most characteristic fossils at the Chillesford Church pit are:—

Turritella terebra.
Natica catena.
Leda oblongoides.
—— *lanceolata.*
Nucula Cobboldiæ.
—— *tenuis.*
Cardium edule.
—— *grœnlandicum.*
Mactra ovalis.
Tellina lata.
—— *obliqua.*
Mya truncata.

[1] Hence the former name of Fluvio-marine Crag for these beds.

[2] The upper bed at Bramerton has been generally reckoned much newer than the lower one. There is, however, little difference between the two, except that *Leda oblongoides*, *Astarte borealis* and *A. compressa* are somewhat more common, and land and freshwater shells less so in the upper than in the lower bed.

A large proportion of the bivalves occur with both valves adherent, but not specially in the position of growth. The deposit does not represent, in my opinion, an undisturbed sea-bottom. The shells present all the appearance of having been drifted; they may have been brought up by the scour of the estuarine tides, and buried while living, or soon after death, in the tidal sediment.

The fossils of the Chillesford Church pit are in a decayed condition, resembling those found in freshwater strata, and contrast strongly with the much better preserved shells of the marine portion of the Crag. This is in harmony with the theory of the estuarine (brackish water) origin of the Chillesfordian deposits.[1] When examined under the microscope, the grains of sand composing the matrix in which these fossils occur are seen to be less rounded than those of the beach-sands of the Red Crag. No glauconite occurs in the Chillesford Sand, and grains of flint are rare in it (see Mr. Lomas's Report, p. 743). In his opinion the material which composes this deposit may have come from a distant source.

For the latest of the Crag-deposits of East Anglia, that of Weybourn and Belaugh, I have proposed the name Weybournian.

These beds, which are characterized by the appearance for the first time in the Crag basin of the recent species, *Tellina balthica* (in the most extraordinary profusion), owing possibly to the opening up of communication with some area,[2] perhaps the southern part of the Baltic, where it had previously established itself abundantly, contain the poorest, as well as the most recent and northern fauna of any of the different horizons of the Crag.

In my paper on the Pliocene deposits of Holland,[3] I suggested that the pebbly gravels grouped by Searles V. Wood, Jun. and myself as the 'Bure Valley Beds' might possibly include deposits of different ages. I now confine the term Weybournian to those only of them in which, on the Cromer coast, and at Belaugh, Crostwick, Rackheath, and Wroxham, *Tellina balthica* is found; and perhaps to the upper part of the Crag-beds near Norwich, regarding the unfossiliferous gravels associated with the Glacial beds in Norfolk, together with the shingle of Westleton, Dunwich, and Halesworth in Suffolk, as distinct (as stated by Prestwich), and probably as Pleistocene.[4]

The mutual relationship of the different deposits is summarized in the following synoptical analysis:—

[1] In his 'Report on the Marine Zoology of Strangford Lough' Rep. Brit. Assoc. (Dublin 1857) p. 110, Prof. G. Dickie noted a similar difference in the condition of the shells dredged within the Lough (an extensive sheet of water communicating with the Irish Sea by an exceedingly narrow channel), and of those met with in the open sea outside it.

[2] See also H. B. Woodward, Mem. Geol. Surv. (1881) 'Norwich' p. 37. The occurrence of a number of characteristic Red Crag shells (although derivative) in gravel-beds on the Aberdeenshire coast tends to show that in the first instance the Red Crag basin communicated with northern seas in that direction.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 772–73.

[4] The separation between Pleistocene and Pliocene in East Anglia is, however, purely conventional, and must not be taken to indicate any important break in the continuity of these deposits.

Analysis of the Molluscan Fauna of the different Horizons of the Crag. (Characteristic and abundant species only.)

	Not known living. per cent.	*Living only in distant seas.* per cent.	*Southern.* per cent.	*Northern.* per cent.	*Northern and Southern.* per cent.
Gedgravian.....	38	4	26	1	3
Waltonian	36	4	20	5	35
Newbournian...	32	5	16	11	36
Butleyan.....	13	4	13	23	47
Icenian	11	—	7	32	50
Weybournian.[1]	11	—	—	33	56

In calculating the various percentages, the more characteristic species of each zone only are taken into account. It is not always easy to draw the line between rare and abundant forms, and possibly the details which might be tabulated by another observer would be somewhat different. I have little doubt however that, in any case, the general results would agree with those here given, and that the foregoing statistics, though they must be regarded as approximate only, justify the conclusions to be drawn from them.

The so-called Forest-bed Series of the Cromer and Kessingland coasts, shown by Mr. Clement Reid to consist of alternations of fresh-water and estuarine strata, may be known as Cromerian.[2] These beds are equally distinguished by the southern character of their fauna from the underlying Weybourn Crag with its boreal mollusca, on the one hand; and from the *Leda-myalis* Sands, and the Arctic Freshwater Bed with *Salix polaris* and *Betula nana*, on the other. These three groups of deposits indicate a distinct change in climatal conditions—an interruption, for the time, of the gradual refrigeration of the Crag Period, similar to that of the Interglacial episodes of the Glacial Epoch.[3] In the case of the Forest-bed, as in that of the Crag, it is necessary to count specimens rather than species. Northern forms are very rare at the former horizon, *Gulo* and *Ovibos*, for instance, being known from unique examples only, while the remains of Southern mammals, such as *Elephas meridionalis*, are exceedingly common.[4]

These Forest-bed fossils, always fragmentary, occurring either in estuarine or fluviatile mud, and flood-gravel, although they do not necessarily represent the mammalian fauna of Norfolk at the period in question, but rather that of the Rhine Valley to the south, still show clearly, I think, that the climate of North-western Europe was

[1] The above figures do not adequately represent the modern character of the Weybournian fauna. If individuals could be counted rather than species, the recent shells would form more than nine-tenths of the whole: the specimens of *Tellina balthica* alone far outnumbering all the others put together.

[2] See Renevier's 'Chronogr. géol.' 2nd ed. (1896) of his 'Tableau des Terrains sédimentaires.'

[3] Prof. James Geikie believes that the Weybourn Crag represents the lowest Boulder Clay of Southern Sweden: see his 'Great Ice Age' 3rd ed. (1894) p. 479, also pp. 336 *et seqq.*

[4] I did not give, in my paper on the 'Pliocene Deposits of Holland' Quart. Journ. Geol. Soc. vol. lii (1896) p. 774, such weight to these considerations as I now think they deserve.

not then arctic.[1] Moreover, the Forest-bed flora, as Mr. Reid has told us, was similar to that of Norfolk at the present day.[2]

On the contrary, the *Leda-myalis* Sands, which contain also *Astarte borealis*, seem naturally to group themselves with the Arctic Freshwater Bed, as belonging to the same epoch and originating under similar climatal conditions. Both should be regarded, I think, as Glacial, rather than as Pliocene.[3]

IV. The Derivative Mollusca of the Red Crag.

Whether or no any considerable proportion of the Red Crag mollusca have been derived from older formations, is a question upon which much difference of opinion has existed. Both Searles V. Wood[4] and his son,[5] as well as Prestwich, believed that many Red Crag shells were extraneous (the lists of such forms given by them having, however, little in common); Prestwich, indeed, expressed the extreme opinion that all species which occur in the Red but not in the Norwich Crag are so.[6]

While a few forms characteristic of horizons older than the Coralline Crag may be derivative, possibly from submarine shell-banks of Older Pliocene age then existing in the Red Crag sea, I do not now think that the Red Crag fauna has been leavened with an admixture of Coralline Crag species. There are Miocene shells which still live in the North Sea, and it seems more probable that some Coralline Crag mollusca may have lingered on there until Red Crag times, than that any specimens should have been washed out of the former deposit into the latter. We have no positive evidence, moreover, that such has been the case. It is not at Tattingstone, Ramsholt, or Sudbourn, where the Red Crag rests upon, or against the Coralline Crag, or at the stack-yard pit near Shottisham Creek, where fragments of indurated Coralline Crag are embedded in the former, that such specimens are so frequently met with, as in the

[1] During the Weybournian Period there may very probably have been considerable accumulation of snow and ice on the Swiss highlands, the melting of which, when the climate became milder, would produce, especially in spring, sudden and violent floods. Animals frequenting the low pasture-grounds bordering the Forest-bed river and its tributaries would thus be annually caught and swept away. In this manner only can we explain, I think, the presence, in so limited an area, of such enormous quantities of mammalian remains. It may be worth noticing that they seem to occur in beds deposited on the convex side of one of the great bends of the Forest-bed estuary, that is, from Kessingland in Suffolk to Cromer (they are not found, so far as we know, at any great distance inland), where the heaping-up of sediment and wreckage would naturally take place.

[2] Mem. Geol. Surv. (1890) 'Plioc. Beds of Britain' p. 185.

[3] Mr. Reid seems inclined to separate the *Leda-myalis* Sands from the Arctic Freshwater Bed, regarding the one as Pliocene and the other as Pleistocene. The introduction of the latter term was, I have always considered, a mistake. It is not, however, so objectionable as Quaternary.

[4] Quart. Journ. Geol. Soc. vol. xv (1859) p. 32.

[5] '3rd Suppl. Monogr. Crag Mollusca' Pal. Soc. (1882) p. 19.

[6] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 350. Prestwich evidently felt that this argument cuts both ways, and he consequently regarded all Red Crag forms which occur also at any other later horizon, as in what were then called the Sables jaunes of Belgium, or in the Glacial beds, as being proper to the Red Crag, and not derivative.

nodule-bed at Waldringfield and elsewhere, at some distance from any known exposure of the older deposit. Shells from the Coralline Crag are not coated with silicate, as are those from older Tertiary formations, and being composed, as a rule, of pure carbonate of lime, are more or less fragile, so that some of them can only be extracted in perfect condition with the most elaborate care and great difficulty. It is not easy to understand that such fossils could have survived the rough treatment to which, on the derivative hypothesis, they must have been exposed in the shallow Red Crag sea, whose waves reduced a great part of the shells of molluscs then living in it to a mass of indistinguishable fragments.[1] Many of the species formerly looked upon as derivative from the Coralline Crag have been obtained in recent years from the Scaldisian of Belgium,[2] and the still later Amstelian deposits of Holland; and, moreover, we find that in the Norwich Crag, where the idea of derivation is not suggested, some characteristic Coralline Crag forms occur occasionally, in certain localities only.

In the Third Supplement to the Monograph of the Crag Mollusca, published in 1882 (after his father's death), S. V. Wood, Jun. maintained, when dealing with the Crag of Felixstowe (Newbournian), that a considerable number of the species found at that place, including such forms as *Cyprœa avellana*, *Voluta Lamberti*, *Nassa reticosa*, *Purpura tetragona*, *Trophon costifer*, *Pectunculus subobliquus*, and *Artemis lentiformis*, had been derived from the destruction of earlier Red Crag beds (Waltonian) formerly occupying the Newbournian area.[3] I am compelled now to differ from my old friend, though with great regret. The Red Crag deposits, I believe, were strictly littoral, and as the sea was gradually retiring northward, it was rather leaving behind it beds which it had accumulated at an earlier stage, than eroding them.[4] If the shells mentioned above had ceased to exist during the later part of the Red Crag Period, they ought to have been deposited at the base only of the different exposures of the more recent zones: that is, when the sea was (*ex hypothesi*), as it began to occupy a new area, destroying and reconstructing any earlier shell-banks that may have existed there; but this is not the case, so far as I know.

The species just named, supposed by Wood to be Waltonian only, occur, moreover, in every part of the Red Crag, and at localities like Butley, the fauna of which has not been generally thought to contain derivative shells.[5]

[1] The rolled and worn condition of some of the specimens supposed to have been derived from the Coralline Crag appears to me an argument against, rather than for, their extraneous origin.

[2] 41 out of the 104 species regarded by Wood as derivative, and 27 out of the 46 given by Prestwich as such, occur in the Belgian or Dutch beds. Of the rest, I have found about 30 at Little Oakley or Beaumont.

[3] S. V. Wood, Jun. and I had suggested a similar view in 1872, '1st Suppl. Crag Moll.' Monogr. Pal. Soc. p. vii.

[4] It must be admitted, however, that the Red Crag south of the Stour has been much denuded.

[5] It is, of course, possible that, in the constant rearrangement by the waves of the shelly material composing the beaches of the Red Crag sea, some specimens may have found their way from the Waltonian to the Newbournian,

V. The probable Conditions under which the Red Crag Deposits originated.

The Coralline Crag deposits are of two kinds: first, the shelly sands, principally organic, the subject of my former paper, originating as submarine banks in water of a moderate depth; and next, coarse rolled material, containing mammalian and other derivative fossils, the littoral drift of that period, accumulated as the basement-bed of the formation, at a time when strong currents from the south or south-west were entering the Crag basin, and the beach was consequently travelling from south to north.[1] The latter deposits, known *in situ* at Sutton only, where they occur at the base of the Coralline Crag, represent the earliest invasion of East Anglia by the Pliocene Sea. As submergence proceeded, and these basement-beds were covered in places by shelly sands, the shore-line was carried somewhat to the west, where accumulation of littoral débris still went on, contemporaneously with that of the former, farther from the coast.

At the close of the Gedgravian (Coralline Crag) Period, an upheaval of the southern part of the Crag area took place, causing some denudation, apparently greatest towards the south, as the outliers of Coralline Crag in that direction, at Tattingstone, Ramsholt, and Sutton, are small and probably fragmentary. This denudation destroyed any of the shelly sands (with the exception of these outliers) that may have existed in that part of the Crag district; but the boxstones and other débris associated with them, better able to stand the wear-and-tear of the advancing sea, were preserved, and went to form the basement-bed of the succeeding Red Crag.[2] That the sources from which they were obtained were cut off before the Red Crag Period (possibly by the southern elevation which destroyed the communication between the North Sea and the English Channel, and interrupted the tidal currents from the south till then existing) is shown by the fact that no such littoral material is found in the Red Crag, except towards the base of the formation. If we adopt the view that the mammalian remains contained in these basement-beds, equally with the mollusca of the boxstones with which in Suffolk they are found, are derivative,[3] that they were brought into the Crag area by currents, or by the travel of the beach, at the commencement of the Gedgravian Period, having been derived principally from Pliocene strata older than the Coralline Crag formerly existing to the south,[4] and that the nodule-beds originally

or from the Newbournian to the Butleyan district. The subject is perhaps one upon which there is room for a difference in opinion; on the whole, however, I believe that the lists of shells from the various Red Crag localities correctly represent the molluscan fauna of each zone.

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 315.

[2] See also H. B. Woodward, 'Geol. Engl. & Wales' (1876) p. 285.

[3] We could hardly expect them to occur so abundantly in a marine deposit, if they were not derivative: the remains of land-mammalia are not usually found under such conditions.

[4] Mr. P. F. Kendall and I found in September 1899, on the beach at Folkestone, fragments of indurated ferruginous sandstone, of composition similar to that of the boxstones, which had fallen down from beds of Lenham (Diestian) age at the summit of the cliff.

containing them were subsequently reconstructed, it removes the difficulty of supposing that animals of an older and southern type, such as *Mastodon*, lived in this country, not only during the Coralline and Red Crag Periods, but during that of the Norwich Crag also, co-existing with the comparatively modern molluscan fauna of the latter, and with arctic shells like *Astarte borealis*, *Cardium grœnlandicum*, and *Tellina lata*. On the other hand, no remains of this pachyderm have been found in the closely connected estuarine (Forest-bed) deposits of the Cromer coast, although the great river to which these were due drained an area far south of Great Britain.[1] There is indeed no more evidence for the existence of *Mastodon* in England during any part of the Crag era, than for that of *Hipparion*, or of the Eocene *Hyracotherium*, the fossil remains of which are found with it in the nodule-beds.[2]

[1] Prestwich believed that most of the mammalian remains which occur in the Red Crag are derivative, 'Geology' vol. ii (1888) p. 422.

[2] The theory of the existence of *Mastodon* in England during the Icenian (Norwich Crag) Period rests principally on the alleged discovery of the entire skeleton of that animal at Horstead, Norfolk, in 1820; see H. B. Woodward, Mem. Geol. Surv. (1881) 'Norwich' p. 57.

Nearly forty years ago I visited Horstead with my friend the Rev. John Gunn, for the purpose of investigating the matter on the spot, and came away with a strong opinion that the evidence in its favour was of the most unsatisfactory character. All that could be proved was that a number of bones had been found on the surface of the Chalk, which (we were told) were taken away on a cart; but they were not submitted to the examination of any competent observer. Some time after, a single tooth, said to have been that of *Mastodon*, and to have been obtained at the same time, found its way, at second hand, into the possession of the Rev. James Layton of Catfield, a village 8 miles from Horstead, and upon this one specimen, and some subsequent hearsay statemen s of the workmen, the story of the supposed discovery has been founded. A railway-truck, however, rather than a cart would have been required to remove the skeleton of such an animal, or any considerable part of it. At that time excavations were being made at right angles to the River Bure, and extending some way back from it, of the size and form of a deep railway-cutting, to enable barges to pass from the river to obtain chalk. There was no cart-road by the side of these canals, so far as I remember, but only a small footpath. Sections of Chalk, covered by thick beds of Crag sand, were exposed in this way, the quarrymen removing a few feet of the latter at a time, so as to uncover a narrow shelf of the Chalk just sufficient for them to work on. Had the skeleton of a great pachyderm been present, 'lying on its side' as stated, it would have taken many months to have got it out, as the cuttings were carried back but slowly, and the Vicar of Catfield would have had every opportunity of seeing some part of it *in situ*. It seems clear that when he visited Horstead, which he says he did 'at the first opportunity,' all traces of the alleged discovery had been removed. It is perhaps worthy of notice that no mention is made of the finding of tusks, which, even if decayed, would certainly have attracted attention, or of more than one tooth. No skeleton of any vertebrate, or even a portion of one, has ever been recorded from the Norwich Crag, the mammalian remains met with in that deposit being fragmentary, and, as a rule, worn. Specimens of the teeth of *Mastodon* have occurred at other places at the base of the Norwich, as of the Red and Coralline Crags, and the Horstead case has, I submit, neither more nor less evidential value than the rest. The want of correspondence between the terrestrial mammalian fauna of the Forest-bed and that of the stone-bed at the base of the Norwich Crag, is, I think, worthy of notice. Out of more than 40 species enumerated in Mr. E. T. Newton's list from the former (excluding doubtful identifications) and 12 from the latter, only 4 are common to both.

The marked difference between the shelly marl of the Coralline Crag, containing only about 12 per cent. of exceedingly fine inorganic material, and the much coarser quartzose sands of the Red Crag, points to some change in the geographical conditions of the Crag basin. In the Coralline Crag, we have the spoil of the sea-bottom, principally organic: shells and shell-fragments heaped up in submarine banks by currents; in that of the Red Crag, there is, in addition to shelly débris, a large percentage of inorganic material derived from coast-erosion, and sediment brought down by rivers, which afterwards accumulated against, or near to the shore.

In a paper which I have quoted on a former occasion,[1] Mr. W. H. Wheeler gives his reasons for believing that in our shallow seas at the present day very little permanent movement of sand derived from coast-waste takes place below low-water mark, the coarser part of such material only being carried along the shore by tidal action, and, further, that the supply of such littoral drift is exceedingly limited. If this be so now, when many parts of the English littoral are fringed by cliffs of Glacial sand and sandy clay, still more must it have been so in East Anglia during the Later Pliocene Period, when strata of Eocene clay formed the margin of the Red Crag sea. It does not, therefore, seem probable that the waste of the land by wave-action could, of itself, have supplied material for the inorganic portion of the enormous mass of sandy Crag which covers so much of Suffolk and Norfolk. There is no evidence that any river entered the English Crag area during the deposition of the Gedgravian Beds, but the contrary may have been the case during the Red Crag Period.

My friend Mr. Joseph Lomas, F.G.S., to whose researches, with those of Prof. Herdman and his colleagues of the Liverpool Biological Society, on the 'Floor-deposits of the Irish Sea,' students of the Crag owe so much, has very kindly undertaken the microscopical and chemical examination of material taken from different parts of the Red Crag and Norwich Crag areas, a task involving much labour and skill, for which, and for the Report appended to this paper (p. 738), my best thanks are due. His researches, showing that the sandy material of the different zones of the Red Crag, and to a great extent that of the Norwich Crag also, is identical in composition throughout, except that the latter contains more mica, as was previously known, tends to establish the generalization that all these beds were deposited generally (except as explained on p. 735) under similar geographical conditions.

It is interesting to notice that many of the minerals which Mr. Lomas has found in the Crag sands, such as garnet, rutile, zircon, tourmaline, ilmenite, and others, are common in the Tertiary deposits of Belgium,[2] having been derived, according to M. Rutot, from Cambrian rocks in the Ardennes, in which, he says, garnets in small crystals are especially abundant.

[1] 'Littoral Drift: in its Relation to the Outfalls of Rivers, &c.' Proc. Inst. Civ. Eng. vol. cxxv (1896) pp. 2–32.

[2] The occurrence of these minerals is, however, very widespread.

The Red Crag deposits rest against, rather than upon, the Coralline Crag. At Sutton, the well-known case of a bed of *Mytili* in place, with adherent valves, indicates, in Prestwich's opinion, an old shore-line.[1] Both the small outlier of Coralline Crag at Sutton, to which near tide-marks this colony of mollusca attached themselves, and the larger one extending from Gedgrave to Aldeburgh, which does not appear to have been submerged by the Red Crag sea, must have formed, at that time, islands in it. We have therefore a datum-line, more than 12 miles long from south-west to north-east, by which we may fix, with some approach to accuracy, the depth of the shallow water in which the Red Crag originated.[2] Messrs. A. & R. Bell, however, have expressed the opinion that the Red Crag fauna is at some localities, as at Waldringfield, of a deeper-water character than it is at others.[3] If this were so, it would indicate a difference, not in the former depth of the sea at such spots, but in the direction of the currents, or the strength of the wave-action which prevailed there.[4] No instances occur in the Red Crag of an undisturbed sea-bottom, except the unstratified bed at the base of the section at Walton Cliff, and one or two similar cases on a smaller scale. The fossils of the Red Crag are, with these few exceptions, the drifted and stratified shells of dead mollusca, deposited either against the shore, or in shallow water in proximity to it.

At the present day, it is in land-locked or sheltered bays, or within the embouchures of estuaries, that, on the English coast, sandy sediment is mostly accumulating. Along those parts that are exposed to the action of tidal currents, the beach travels, but on the whole it does not increase in extent seaward; sheltered bays, however, act as catchment-areas, arresting its progress, and it is under such circumstances heaped up against the shore by wave-action, or it accumulates in shallow water as banks or shoals.

Where rivers have been discharging in the vicinity, accumulation has naturally gone on to a greater extent, and in proportion to the amount of sediment brought down by them, now, or at some former period: as, for example, on the Lancashire coast in Morecambe Bay, or in the estuaries of the Dee and Ribble; and on the eastern coast of Great Britain, in the Wash, and the estuary of the Thames.

Dead shells often accumulate in such sheltered places, as in Morte Bay on the north-western coast of Devon, where the beach is covered with them; or on Padstow Sands, of which they form

[1] Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 340. Mr. P. F. Kendall noticed a similar bed of *Mytili* in the pit at Sudbourn, No. 19 of my former paper, Quart. Journ. Geol. Soc. vol. liv (1898) fig. 4, p. 326, where the Red Crag rests upon the Coralline Crag.

[2] Prestwich observed, moreover, ripple-marks, indicative of a shore from time to time uncovered by the tide, in the Crag at Bawdsey, Quart. Journ. Geol. Soc. vol. xxvii (1871) p. 327 & fig. 7.

[3] Proc. Geol. Assoc. vol. ii (1873) p. 193.

[4] A similar phenomenon may now be observed on our beaches, where the shells of some species are cast up at one spot, and not at another.

90 per cent., being blown up from the sea-bottom by gales of wind.[1]

At present the coast of East Anglia is singularly destitute of drifted shells. Except in the extreme north-western corner of Norfolk, between Hunstanton and Wells, which is exposed to north-westerly winds, one may walk along the beach for many miles and hardly find a specimen. It is evident, therefore, that conditions other than those of the present day must have obtained along the western shore of the North Sea during the Newer Crag Period. When we cross the North Sea to Holland, however, we find dead shells everywhere: along the beach; fringing the shores of estuaries; and accumulating in channels through which tidal currents no longer run. So enormous is the amount of these débris that carts are constantly at work removing them from the beach, and powerful steam-dredgers dredging them from the estuaries,[2] to be burnt for lime. On the flat sandy beaches of the open coast-line, as at the southern extremity of the island of Texel, the shells lie, mixed with sand, in nearly horizontal sheets; while along the shores of estuaries, and against sand-banks, and in channels of former bays now being silted up, the débris (composed of fragmentary as well as of perfect shells) are more or less obliquely-bedded. This accumulation of shelly sand is attributed by Dutch geologists, and I think with reason, to the prevalence of gales from the west. If this be so, it would seem that strong winds from the east, rather than from the west, must have prevailed on the shores of East Anglia during the Newer Crag Period. In a short paper read before Section C of the British Association at Dover, published in abstract only,[3] I gave my reasons, from a meteorological standpoint, for thinking that such was probably the case, and I hope hereafter to be able to deal more fully with the subject. It seems, however, that in the conditions now existing in Holland we have a counterpart of those of East Anglia during the Later Pliocene Epoch, and may thus obtain an explanation of the means by which so enormous a quantity of shelly débris then and there accumulated.

S. V. Wood, Jun. suggested in 1864[4] that the oblique bedding common in the Red Crag indicates that it originated, to a great extent, as a beach-deposit.[5] The frequent south-south-westerly dip of the highly inclined laminæ shows, however, that the Red Crag could not have been wholly accumulated against the southern shore of the North Sea while it was gradually retreating northward. The tectonic movement which affected the Anglo-Belgian basin must, therefore, have taken the form, not so much of a continuous subsidence in one direction, and an upheaval in the other, as of a

[1] Christopher Claxton, Minutes of Evid. in Parl. Report on Harbours of Refuge (1858) p. 98.

[2] About 3,600,000 cubic feet of these shells are dredged yearly, at one spot.

[3] Rep. Brit. Assoc. (1899) p. 753.

[4] Ann. Mag. Nat. Hist. ser. 3, vol. xiii (1864) p. 185.

[5] It is oblique rather than current-bedding that is characteristic of the Red Crag.

succession of foldings which shifted the area of deposition from time to time. In this way, I think, a series of land-locked bays were formed, one after the other, and were successively silted-up by sediment, deposited, partly against the shore, and partly as banks or shoals in the shallow water. Under such circumstances the beds would dip, of course, in different directions on the opposite sides of the bays.[1]

The position which these bays of the Red Crag Period successively occupied may be, I think, approximately defined. A reference to the map (fig. 3, p. 714) will show that the geographical divisions of the Crag, indicated by the differing character of their molluscan fauna, are bounded, broadly speaking, by the estuaries of the Stour, Orwell, and Deben, which radiate from a point slightly east of Harwich: the Waltonian Beds being confined to Essex, south of the Stour; the Newbournian occurring principally between the Orwell and the Deben; and the Butleyan being found only to the east of the latter.

If S. V. Wood's opinion be correct, that the Crag of Bentley (which possibly represents that of the unexplored district between the Stour and the Orwell) is intermediate in age between the Crags of Walton and Newbourn, the whole of the Red Crag divides itself into zones, the geographical limits of which coincide nearly with those of the estuaries named.[2] Thirty-five years ago his son expressed the opinion that the principal valleys of the East of England form more than one series of concentric and inosculating arcs, caused by tectonic disturbances which had their foci in the South of England,[3] and at a later date he returned again to the subject.[4] The Crag district has certainly been subjected to some such folding process, and the coincidences alluded to may possibly hereafter prove worthy of further notice.

Although it appears, from the researches of Mr. Lomas, that there is little difference in composition between the sands of the Red and the Norwich Crags, except that the latter are more micaceous (implying, I think, a closer connection, during their deposition,

[1] Instances of the silting-up of such bays in recent times are by no means uncommon, especially in Holland. There is an area south of the Hoek van Holland, for example, which seems to me to represent exactly the condition of East Anglia during the Red Crag Period. What was formerly a bay or inlet is now nearly choked with shelly sand, which is, however, still accumulating along the shores of the Maas estuary, on the edges of shoals, and in channels formerly occupied by the river, being often bedded at a high angle, dipping of course in different directions as the deposits follow the sinuous winding of the banks. Farther inland, also, are similar beds of shelly sand—the deposits, under similar conditions, of an earlier, though geologically recent period.

[2] The Red Crag sea does not seem to have extended westward beyond the limits of the Eocene beds, so as to reach the Chalk outcrop, or littoral accumulations of chalk-flints would have resulted. Indeed at Sudbury, the westernmost point to which the Crag has been traced, it shows evident signs of thinning out against the old shore-line.

[3] Phil. Mag. ser. 4, vol. xxvii (1864) p. 180.

[4] MS. paper in the Geological Society's Library.

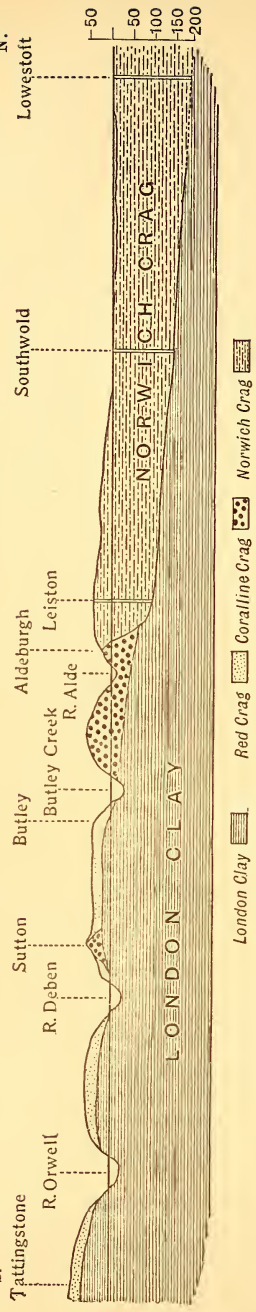


Fig. 5.—*Section from Tattingstone to Lowestoft, showing the comparative thickness of the Red Crag, and of the Norwich Crag of East Suffolk, as also the rapid thickening of the latter northward. (Glacial deposits are omitted.)*

between East Anglia and the Rhine, from rocks in the basin of which the mica was probably derived), it appears that the conditions under which the two formations originated were somewhat different. While the Red Crag was apparently deposited in confined bays or inlets, the Norwich Crag beds occupy a much larger and more exposed area (see map, fig. 3, p. 714). The latter are not so constantly fossiliferous; they are more or less horizontally stratified; and they never present the highly inclined beach-like bedding of the Red Crag. The Red Crag, moreover, where its junction with the London Clay is exposed, as is the case in places from Tattingstone and Walton in the south, to Bawdsey, Ramsholt, and Sutton in the north, does not attain a greater thickness than about 20 or 25 feet. At Butley and Chillesford, farther north, where the base of the Crag dips below the water-line, it may perhaps be somewhat. although not much, thicker. When we pass north of Aldeburgh, however, where the Icenian (Norwich Crag) Beds come on, we find that the Crag thickens very rapidly, attaining 134 feet at Leiston[1]; at Southwold, 9 miles farther northwest, it reaches 140 feet below sea-level, with a total thickness of 147 feet[2]; while in a recent boring at Lowestoft, mentioned by Mr. C. Reid, its base was not reached at 180 feet.[3]

Deposition and subsidence in East Anglia during the Norwich-Crag era seem to have proceeded *pari passu*, as was the case during the Pliocene Period in Holland, although not to so great an extent as in that country. This state of things was due in both, however, to the same cause. The greatest

[1] From information kindly supplied by Mr. W. H. Dalton, F.G.S.
[2] Mem. Geol. Surv. (1887) 'Southwold' p. 79.
[3] Summ. of Progress of Geol. Surv. for 1898 (1899) pp. 145-46.

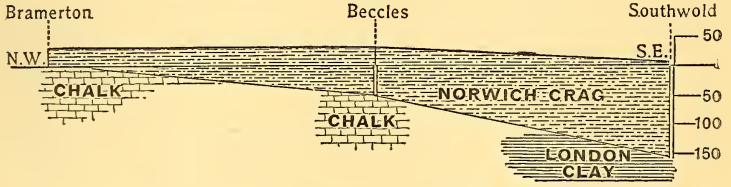
subsidence recorded is that evidenced by the deep borings at Amsterdam, where the base of the Amstelian deposits was not reached at a depth of 1100 feet; and it died out on the south-west, that is, towards the East Anglian margin of the Crag sea.[1]

This movement of the Pliocene sea-bottom in Holland was coincident with, if not caused by, the accumulation of the sediment brought into it by rivers; and as the Dutch deposits represent the ancient delta of the Rhine and its affluents, it seems more than probable that the micaceous sands of the Norwich Crag, although not contemporaneous with the Amstelian strata, also may have had a similar origin: the heaping-up of sand, and of dead shells against the western margin of the Crag sea, being favoured by the prevalence at that time of easterly winds.[2]

I have given my reasons elsewhere for believing that at a somewhat later period the estuary of the Chillesford Clay formed one of the outlets of these rivers,[3] as did afterwards also (as pointed out by Mr. Clement Reid) the estuary of the so-called Forest-bed of the Cromer coast.[4]

The following diagrammatic section, drawn from Bramerton near Norwich to Southwold, shows the increasing thickness and dip of the Icenian Beds in a south-easterly direction, that is, towards Holland.

Fig. 6.—*Section from Bramerton, near Norwich, to Southwold.*



[The Glacial deposits are omitted.]

It should also be noticed that the gradually increasing dip and thickness of the Icenian Beds from south to north is of the same character as that of the Amstelian deposits of Holland, as shown by the deep borings at Utrecht, Amsterdam, and elsewhere.[5]

VI. Summary.

The line separating the Older and the Newer Pliocene deposits of the East of England should be drawn between the Lenham Beds (zone of *Arca diluvii*) and the Coralline Crag, instead of between the latter and the Crag of Walton, as hitherto.

[1] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 753, 761 & figs. 3–4.

[2] Gradual and concurrent subsidence seems to be a common feature of delta-formation in all parts of the world.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) p. 770.

[4] Mem. Geol. Surv. (1882) 'Cromer' p. 57.

[5] Quart. Journ. Geol. Soc. vol. lii (1896) fig. 4, p. 761.

The Upper Crag deposits are not of uniform age, as believed by Prestwich, but arrange themselves in zones, characterized by a gradually diminishing percentage of extinct and southern, and an increasing percentage of recent and northern mollusca.

Although these zones contain faunas sufficiently distinct to justify their separate classification, they all form part of a more or less continuous and closely connected series; they group themselves in horizontal, and not in vertical sequence, the older deposits occurring invariably towards the south of the Crag area, and the newer towards the north.

The term Red Crag is too comprehensive, and, when we attempt to correlate the East Anglian deposits with those of Belgium and Holland, inconvenient. While retaining it for general use, it seems desirable to adopt for its different horizons some more definite and distinctive names. The classification tabulated on p. 708 is therefore proposed.

The Oakley zone is a new horizon of the Crag, intermediate in age between the Walton Bed, with its southern fauna, and the Suffolk Crag in which northern mollusca are more or less common; it represents the period before the southern shells had begun to die out, when a few boreal forms, invading the Anglo-Belgian basin from the north, were establishing themselves in greater or less abundance in the Crag sea.

The earliest indication of the conditions obtaining during the Red Crag Period is afforded by an unstratified bed at the base of the Walton cliff-section, not now visible, originating in comparatively shallow water, where a colony of mollusca lived and died. No trace of this bed has been met with in deposits of Waltonian age in other parts of Essex.

A slight upheaval of Northern Essex afterwards took place, causing the Walton area to form the edge of a land-locked bay, which was gradually silted-up by material, brought down possibly by a river entering the Crag sea at no great distance. To some extent the silting process went on from north-north-east to south-south-west, the shelly sand being obliquely bedded against the northern shore of the Waltonian bay, or deposited in the form of banks or shoals within it (see map, fig. 3, p. 714). A subsequent but slight submergence permitted the deposition of horizontal beds upon the obliquely-bedded Crag,[1] and carried the sea over a gently sloping shore of London Clay to the west towards Beaumont, and afterwards northward to Little Oakley, some erosion of the Eocene beds taking place as the sea encroached upon the land.[2] The bed of pebbly gravel underlain by clay, forming the upper part of the

[1] A similar state of things is to be seen in the stack-yard pit at Chillesford, where horizontally-bedded Crag rests upon beach-Crag, indicating, as at Walton, the gradual subsidence of the beach and the encroachment of a shallow sea over the adjoining land.

[2] The fact that phosphatic nodules are principally found towards the base of the Crag seems to show that it was when the position of the Red Crag sea was shifted, and the sea invaded a fresh area, that denudation of the Eocene strata took place; and that this denudation ceased when the new bay began in its turn to be choked by the deposition in it of shelly sand.

Walton cliff-section (fig. 2, p. 711), with the gravel of Clacton, a few miles to the south, may possibly belong to a subsequent stage of the Crag, when the Walton area had been slightly elevated, and was occupied by the embouchure of the river before referred to, the Crag sea having retreated into Southern Suffolk, destroying as it did so any Older Pliocene beds which may have existed there, except the littoral deposits of the Coralline Crag sea with their derivative fossils, which were reconstructed so as to form the basement-beds of the Newbournian Crag at Waldringfield and elsewhere.

The Newbournian stage is separated from the Waltonian, not only by the time required for the tectonic movement which carried the Crag sea into Suffolk, but for the arrival in the Crag basin of further immigrations of northern mollusca. The Newbournian bay was in its turn silted-up by material lithologically identical with that of the Waltonian Beds. To a great extent the beach- or shoal-deposits of this period grew also from north-north-east to south-south-west,[1] the small outliers of Coralline Crag at Sutton and Ramsholt, and the main mass of that formation from Gedgrave to Aldeburgh, forming at that time rocky islands in the sea.

Disturbance again ensued, but caused a subsidence towards the east, so that a part of the Crag sea shrank into a narrow inlet, extending from Chillesford to Bawdsey, bounded on the east by the great bank of Coralline Crag against which the Butleyan deposits rest. This bank was then more or less of the same extent and form as at present, for Red Crag-beds fringe it on the eastern or seaward side also, at Orford and Sudbourn. A small stream may have entered the Butley inlet from the north, as Mr. Alfred Bell discovered many years ago at that locality a seam containing land and freshwater shells.[2] This bay was in its turn choked with sediment, much of the lower part of it bedded at a high angle, as if against the edge of a steeply sloping shore or shoal, and in places with a south-south-westerly dip, but overlain, as at Walton, by Crag horizontally stratified. If the accumulation of sediment in this part of the Crag area commenced from the north, as seems possible, the beds at Bawdsey, in which *Cardium grœnlandicum* is so abundant, may be the latest of the Red Crag Series, and more recent than those of Sudbourn or Butley. For a similar reason, the Crag of Felixstowe may be somewhat newer than that of Waldringfield, farther inland: a view which, from the study of the molluscan fauna of these two places, seems to be not improbable.

The Norwich Crag-beds (Icenian) are separated by a considerable interval from any part of the Red Crag. Their molluscan fauna has a much more recent character; they never exhibit the highly inclined bedding so characteristic of the Red Crag, and they attain a much greater thickness than the latter; they occupy an entirely different area, and appear to have originated under somewhat different conditions, being possibly the western edge of the great

[1] See as to this also many of the sections in Prestwich's paper, Quart. Journ. Geol. Soc. vol. xxvii (1871) pp. 329 *et seqq.*

[2] Geol. Mag. 1871, p. 452. Such shells occur also at Hollesley, according to Mr. P. F. Kendall.

delta-deposit of the Rhine, which attains such vast proportions in the subsoil of Holland. The subsidence of portions of Holland and of the North-Sea basin, which went on *pari passu* with the accumulation of this delta, seems to have died out towards East Anglia: the Icenian deposits becoming gradually thinner as we trace them southward and westward.

The Weybournian Crag occurring only north of the map (fig. 3, p. 714), divided from the Icenian by the estuarine Chillesford Beds, does not extend into Suffolk, and is probably, as explained on p. 724, distinct from the shingle of Westleton and Dunwich, which may be of Glacial age.

Although a few species of mollusca found in the Red Crag which seem characteristic of an earlier horizon may possibly have been derived from Older Pliocene beds, it does not appear to me that the Red Crag has been leavened by an admixture of Coralline Crag forms. The mollusca of the boxstones which occur in places at the base of both the Coralline and the Red Crags, equally with the Eocene fossils found with them, are, however, derivative in the Crag, as are the remains of *Mastodon*, and other mammals which seem quite out of place in these comparatively recent deposits.

The conditions under which the Newer Crag-beds originated seem to exist at the present day in Holland, where sandy material brought down by rivers into the sea has been thrown against and upon the shore, together with the shells of marine mollusca, and probably by winds from the west. From meteorological considerations it seems possible that strong gales from the east may have prevailed over the Crag area during the latter part of the Pliocene Epoch. This would explain why shelly sand accumulated in such enormous quantities on the East Anglian margin of the North Sea at that period, while at the present day the eastern coasts of Norfolk and Suffolk are almost wholly destitute of such débris.

The so-called Forest-bed, with its southern fauna, indicates a distinct change in climatal conditions, similar to that of the Interglacial episodes of the Pleistocene Epoch, and should be separated, on the one hand, from the Weybourn Crag, and on the other (as urged by Prof. James Geikie [1]) from the *Leda-myalis* Sands and the Arctic Freshwater Bed. The latter two seem naturally to group themselves together, and with the Glacial deposits.

VII. Appendix.

Report *on the* Inorganic Constituents *of the* Crag.

By Joseph Lomas, Esq., A.R.C.S., F.G.S.

Red Crag.

For the purposes of this enquiry the proposed zones of the Red Crag—Waltonian, Newbournian, and Butleyan—may be taken together, as no essential differences in the contained minerals can be detected.

Very marked distinctions in colour are noticeable in different

[1] 'Great Ice Age' 3rd ed. (1894) p. 336, etc.

localities, but these largely depend on varying degrees of impregnation with iron. The iron-staining undoubtedly took place after the beds were deposited, and differences in amount can be traced to the flow of water containing iron in solution. Thus, it is found that where the Crag rests upon a clayey foundation, as at Beaumont, the line of parting has formed a channel along which water has flowed.

In some cases, as is well seen in the pit near Beaumont Hall, the lines of infiltration run across the bedding in wavy lines. It is evident that water percolating through porous rock must trend towards an outflow. When a line of flow has once been established, most of the water will move through certain channels and, carrying iron in solution, there will be a tendency to form pipes by the deposition of iron-oxide in the interstices of the sand.

Where pits have been for a long time unworked and a cliff of Crag has been left exposed, the porous rock has served as a passage for surface-water, which oozes out from the face of the section. Here the staining can be directly associated with lines of flow. In some instances the iron-oxide has cemented the sand and shells together, and, where a part of the cliff has been overhanging, ferruginous stalactites and stalagmites have formed. This is well shown in the pit below the church at Chillesford. The stalactites are hollow tubes, frequently branched, and water can now be seen dripping through them.

One case of infiltration is worthy of special mention. It occurs at the base of the section at Beaumont Hall, where the Crag rests directly upon the London Clay. The sand and shells are black, and so thick is the encrusting material that no part of the original fragments can be seen. On treating this material with hydrochloric acid the calcareous interior is removed, but a hollow cast is left composed of iron-oxide. The carbon dioxide, liberated by the action of the acid on the shell, buoys up the cast so that it floats on the surface of the liquid.

Casts of shells are produced which often retain their characteristic markings. Even perfect examples of *Echinocyamus* and polyzoa can be obtained in this way, and some of the latter, such as *Biflustra* and *Cellaria*, show all the delicate features of the original organisms.

The following analyses, made by Mr. C. C. Moore, F.I.C., of Liverpool, show that the black encrusting material is slightly phosphatic:—

No. I refers to the black material from Beaumont;
No. II, given for comparison, is from the same pit, but the material was obtained from the interior of a large *Fusus*;
No. III shows the composition of a lighter-coloured Crag from Oakley.

	I. per cent.	II. per cent.	III. per cent.
Silica, etc. insoluble in hydrochloric acid	44·95	41·58	59·63
Soluble in hydrochloric acid:—			
SiO_2	trace	none	none
Fe_2O_3	5·72	7·73	16·37
Mn_2O_3	·21	trace	trace
$CaCO_3$	48·21	49·82	23·16
MgO	·08	·13	trace
P_2O_5	·21	trace	trace

The abundance of glauconite in the Crag makes it highly probable, as suggested by M. Van den Broeck,[1] that the decomposition of this mineral is the main source of the iron-oxide which forms the staining-material of these beds.

In all places where the Red Crag is exposed, it is seen to be composed of a loose shelly sand. Pebbles occur sporadically, ranging up to 3 or 4 inches in diameter.[2] Flint-pebbles are by far the commonest; they are usually very well rounded. A peculiar hard, brown chalk also occurs along with the flints. Other pebbles consist of pink quartzite, chert, and phosphatic nodules. Rolled clay-galls are found abundantly in most localities, coated with sand-grains, and resembling exactly those which are now being formed on sandy beaches bordering clay-cliffs.

Rolled specimens of a fairly coarse dark brown sandstone may be collected throughout the series, and can be matched with the Diestian Sandstones of Kent. It is not uncommon to find these pebbles bored by molluscs.

A finer-grained dark sandstone also occurs, which contains an abundance of mica. This may be the 'mica-schist' recorded by the late John Brown, of Stanway, as occurring at Beaumont.[3]

The chief object of this communication, however, is to record the rarer constituents to be found in the Crag sands.

In order to concentrate the rarer minerals, the sands were fractionated by means of high-density fluids. At first dilute hydrochloric acid was used, to get rid of the carbonates and to remove the iron-staining from the grains. It was found necessary, however, to treat the material with hot concentrated hydrochloric acid in order to clear the grains for examination. Even prolonged boiling in strong hydrochloric acid was not sufficient for the black material from Beaumont. Possibly some of the minerals readily soluble in hydrochloric acid have been removed by this treatment.

Twenty-five grammes of ordinary Red Crag from Beaumont was treated with concentrated hydrochloric acid. The insoluble part was then divided into fractions by means of Rohrbach's solution:—

	·102 gramme, or	·4 per cent.,	had a density	greater than 2·7;
	·622 „	or 2·5 „	„	less than 2·5;
while	12·25 grammes,	or 49 „	„	between 2·5 & 2·7.

[1] 'Du Rôle de l'Infiltration des Eaux Météoriques dans l'Altération des Dépôts superficiels' Internat. Geol. Congr. (Paris, 1878) Comptes Rendus, p. 188.

[2] A block of flint, cubical in shape and 15 inches across, may be seen lying on the floor of the large pit near Sutton Windmill; and Mr. Harmer states that he met with two or three large unworn flints, weighing 10 or 12 lbs., at Oakley.

[3] He also enumerates agate, chert, septaria, quartz (milky variety), quartz (highly crystalline like that of the Lickey), and flints from the Chalk: Quart. Journ. Geol. Soc. vol. xv (1859) p. 41. See also Prestwich, *ibid.* vol. xxvii (1871) p. 326, where he mentions a large fragment of red granite as occurring at Trimley.

In this sample quartz makes up about half of the total weight of the Crag.

Very much larger quantities were afterwards separated by means of Klein's solution (borotungstate of cadmium).

The fraction of a density above 3·28 contained zircon, rutile, cyanite, andalusite, corundum, garnets, ilmenite, and leucoxene.

The zircon occurs principally as small grains, averaging ·2 millim. in length. The majority of the crystals have sharp clear outlines, but others are rounded or oval in form. This, however, cannot be regarded as the result of abrasion by subaerial agents, as precisely similar rounded grains are found enclosed in the mica which comes down with a lighter fraction. The zircon itself usually contains many inclusions—long brown needles—hexagonal in section, and frequently oriented so that their long axes are parallel to the pyramidal faces.

Dark-brown or reddish crystals of rutile are also common. Most of them are very small, only a little larger than the zircons. Occasionally larger grains are found, having a diameter of ·5 millim. Usually the grains are angular and show crystalline faces, but rounded forms occur among the larger grains.

Cyanite is fairly plentiful, both as rounded and angular grains. The latter are mostly long rectangular prisms with strong cleavages, and often crowded with inclusions of zircon and rutile. The angle of extinction, measured from the prism-faces, is about 31° 30′. Some specimens exhibit a fibrous structure, and appear faintly blue under the microscope. The inclusions usually lie in lines which show extinction when parallel to the cross-wires of the microscope.

Andalusite is not common. It occurs as long, clear rectangular crystals, showing straight extinction and having a bright shagreen appearance.

Corundum occurs as brown or yellow crystals, mostly well rounded.

Garnets are so plentiful in the heavy fraction that the material in the mass has a strong pinkish colour. The grains are nearly always well rounded, and range up to and above ·5 millim. in diameter. They contain many inclusions.

Ilmenite occurs both as angular and rounded grains. It shows the characteristic greyish-black metallic lustre by reflected light.

Leucoxene accompanies the ilmenite as large, white, opaque grains. Sometimes the centre of a grain is black with a white border.

The material separated out by a solution having a specific gravity of 3 consisted almost entirely of

Tourmaline. The grains vary much in colour, but green predominates—emerald-green, pistachio-green, blackish-green; but many are yellow, brown, purple, and a few deep cobalt-blue. The green varieties are mostly angular in form, and often fibrous; the others are, almost without exception, well rounded.

The next fraction, with a density slightly less than 3, contains very little but mica and glauconite.

Both biotite and muscovite occur, though muscovite predominates. Associated with the micas is a dark-green biaxial mineral exactly resembling a mica: it is probably sericite.

Glauconite comes down with this fraction as well as in succeeding separations, even in those lighter than quartz. The heavier forms are opaque, but some of the lighter are translucent and even transparent. By reflected light the opaque varieties are dark-green, with white bands. They often retain the shape of foraminifera, of which they have formed casts.

The felspars, having a density approximating to that of quartz, are liable to be lost; but in the examination of many slides I have found microcline, orthoclase, labradorite, and albite.

Quartz. Even after treatment with strong hydrochloric acid, many of the grains retain a thin staining of iron-oxide. The larger grains only are well-rounded, and some have a very high polish. In size they range from ·05 to 1·5 millim. Inclusions are very common; some grains contain so many that they come down with the heavier separations. Apatite is of very frequent occurrence. Most of the grains are colourless, but amethyst- and amber-coloured specimens may be found. In a few cases only was there noticed a trace of secondary crystallization. Small angular pieces of flint and chalcedony are not infrequent.

The fraction having a specific gravity less than that of quartz consists mainly of glauconite and flint.

In some localities, as at Walton and places to the south of it, the Red Crag is overlain by sands and gravels. A separate examination of these revealed precisely the same constituents as those enumerated from the Red Crag. The only distinctions that I could detect were that they contained few or no shell-fragments; they show very little staining, and the larger pebbles were more numerous. Their general appearance suggests that the Red Crag material has been sifted by strong currents, the finer stuff and shells being removed, and the larger fragments left.

Norwich Crag (Icenian).

More than 3 lbs. of Norwich Crag was treated with heavy fluids in order to concentrate the minerals. Large fractions were obtained, and these have been thoroughly examined with a view to detecting possible differences between the inorganic constituents of the Red and Norwich Crags.

All the minerals stated as occurring in the Red Crag have been found in the Norwich Crag; the latter contains more mica, the grains are not so heavily stained with iron-oxide, and a fine muddy material coats the sand-grains.

Lithologically the Red and Norwich Crags must be regarded as forming one series, deposited under somewhat similar physical conditions.

Chillesford Sand.

Specimens were examined from two localities: the pit behind Chillesford Church, and the brickfield at Aldeburgh, where the sand is seen underlying Chillesford Clay. The minerals from these two localities are exactly the same, the only difference being that the grains are somewhat larger at Aldeburgh.

The sand was fractionated with borotungstate of cadmium, and the various separations were examined separately.

The following minerals occur:—Zircon, rutile, garnet, andalusite, ilmenite, leucoxene, tourmaline (green, blue, and yellow), biotite, muscovite, a green mica, plagioclase-felspars, quartz, and flint.

In striking contrast with the Crag sands, it will be noted that no glauconite was found.

Mica is very abundant, especially muscovite; and grains of flint are rare. Ferro-magnesian minerals except biotite are absent.

Nearly all the minerals enumerated in the foregoing pages are stable in composition, and capable of transport for long distances without decomposition. It would be a fair inference to assume that they have come from a distant source, and probably had their origin in rocks which have undergone extensive metamorphism. Whether they have been directly derived from such rocks would be hard to prove, but the frequent inclusions of zircon, rutile, and other secondary minerals in mica and other substances favours this view.

Discussion.

Mr. H. W. Burrows agreed with the Author's general contention that the Upper Red Crags show a succession of oldest to newest from south to north. This, he believed, could be demonstrated in detail: the pits at Butley being cited as an illustration. There seemed to him a peculiar fitness in the fact that the Author, who had endeavoured to demolish the seven zones established by Prestwich for the Coralline Crag, should now replace them with an equivalent number for the Upper Crags. According to the Author, the whole of the Coralline Crag could be included under one phase—Gedgravian; while it was necessary to define as many as seven distinct zones for

the Upper Crags. The relative values of these subdivisions were by no means equal; and it seemed to him that, if a new term be needed for Coralline Crag, the classical locality of Sutton should take precedence of Gedgrave.

It was difficult to see how the Author's view of oblique bedding could be entirely accepted, having regard to the reversal in obliquity so often seen, and particularly well exhibited at Butley Priory. The speaker alluded to the opinion of the late Dr. Paul Fischer, expressed in conversation at Bordeaux, that the sinistral and dextral forms of *Neptunea antiqua* should be regarded as distinct species. The theory expounded by Mr. Lomas did not appear to offer a complete explanation of the oxidation of the Crag, for it was not clearly explained how it was possible to find so much glauconite in the Crag, if oxidation was due to its decomposition, seeing that where the beds were reddest, glauconite was often most abundant. It was to be hoped that Mr. Kendall would publish his list of the Walton fauna, which would be a valuable addition to our knowledge of faunal distribution in the Crags.

Prof. Sollas congratulated the Author on the success with which he had evolved a connected history from materials so fragmentary as those of the Crag. The shifting of the area of deposition was an important phenomenon, and might be detected in some of the older systems. While false-bedding occurred in beach-deposits, it was far from being exclusively confined to them, and could not therefore be trusted as an indication of littoral conditions.

The President, Mr. P. F. Kendall, Mr. Whitaker, and Mr. Lomas also spoke.

The Author, after thanking the President and Fellows for their kind reception of his paper, said he was glad to find that most of those who had joined in the discussion were able to accept the conclusions which he had reached. Mr. Kendall had very generously consented to allow him to publish his valuable list of Walton shells, compiled some years ago, and this would add greatly to the usefulness and interest of his own lists from Beaumont and Oakley.

Replying to Mr. Burrows, he said that he had given in his paper his reasons for the division of the Red Crag into zones. He employed the term Gedgravian because Gedgrave is the only locality at which none but Coralline Crag deposits occur. At Sutton, both the Coralline Crag and the Red Crag are present, and if the designation Suttonian be used at all, it should rather be for the latter. Nevertheless, for the reasons given, he preferred the term Newbournian for Wood's Red Crag zone of Sutton.

The minerals found by Mr. Lomas in the Crag sands were all common in the Pliocene of Belgium, having been derived, according to M. Rutot, from the Ardennes, garnets, 'en petits cristaux,' being specially abundant. There is much to connect the English Crag-beds with the Rhineland. The cross-bedding of the Crag in the Butley Priory pit is precisely like that which is being produced in a former estuary of the Maas, near the Hoek van Holland, now being silted up with shelly sand.